GODDARD SPACE FLIGHT CENTER

January 11, 2001

New Millennium Program's First Earth Observing Mission (EO-1)

Technology Workshop

USGS Auditorium / Reston, Virginia

. . . Bryant Cramer

Earth Observing-1 Implementation Manager

New Millennium Program

Contents

Section 1

Introduction

Introduction

- ***This is the first of several technology workshops associated with the New Millennium Program's First Earth Observing Mission (E0-1)***
- ***The EO-1 Mission was successfully launched on November 21, 2000:***
  - *Now in position one minute behind Landsat-7*
  - *Contains three land-imaging instruments and eight spacecraft technologies applicable to a Landsat follow-on mission*
  - *Observatory is operating nominally and technology validation is underway*
- ***The purpose of these workshops is to facilitate the transfer of EO-1 technologies into new applications and to efficiently infuse them into future missions***
- ***Consequently, we are associated with the Kick-Off Workshop for the mission to succeed Landsat-7 known as the Landsat Data Continuity Mission (LDCM)***
- ***We believe that EO-1 will flight-validate a number of new technologies that will serve to lower the cost and improve the performance of the LDCM***

Section 2

Meeting Objectives

Agenda

8:30	*Introduction*
8:45	*Meeting Objectives*
9:00	*NMP Perspective*
9:15	*Overview of the EO-1 Mission*
9:45	*Technology Transfer and Infusion Process*
10:15	*Break*
10:30	*Advanced Land Imager*
11:30	*Lunch*
12:30	*Hyperion*
1:30	*Atmospheric Corrector*
2:00	*Science Validation Process*
3:00	*Break*
3:15	*Overview of EO-1 Spacecraft Technologies*
4:15	*Next Steps and Near-Term Schedule*
5:00	*Adjourn*

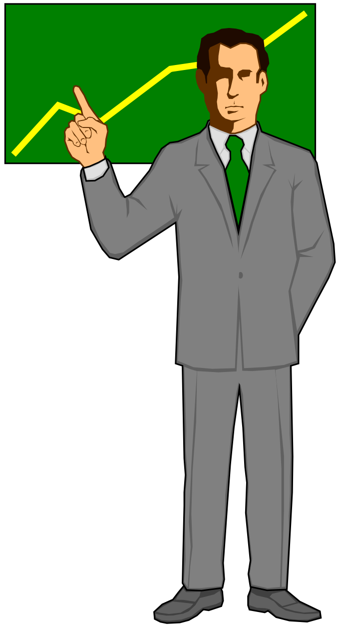
Meeting Objectives

- *Familiarize attendees with the EO-1 Mission and its technologies*
- *Explain the NMP technology validation process and the subsequent technology transfer and infusion into future missions like the LDCM*
- *Present background technical data on all three EO-1 instruments*
- *Review the science validation process associated with the instruments*
- *Summarize the background and status of the spacecraft technologies*
- *Characterize the technology infusion opportunities for each technology*
- *Identify those parties interested in using the EO-1 technologies*
- *Describe tasking opportunities potentially available later in the EO-1 mission*

NASA New Millennium Program Perspective

. . . Christopher Stevens
California Institute of Technology, JPL

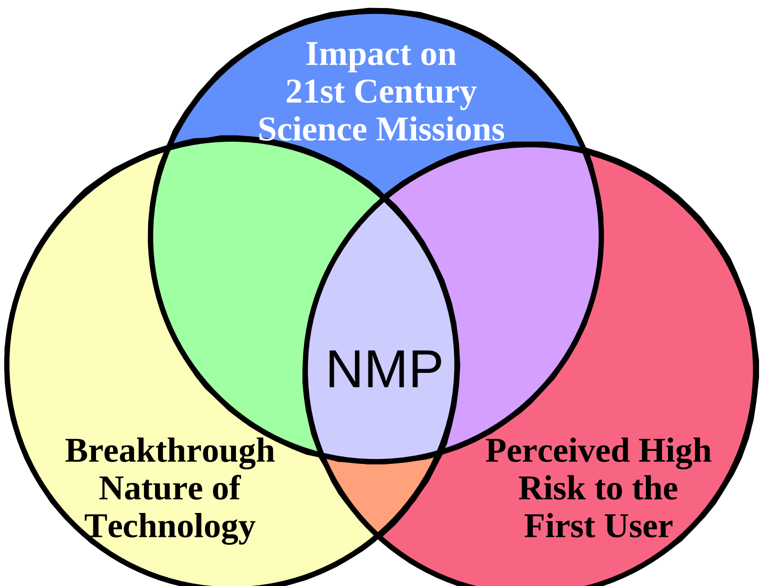
New Millennium Goals



- ***The New Millennium Program (NMP) was established in 1994 to revolutionize NASA's Space and Earth science programs to achieve more capable, less costly missions in the 21st Century by:***
  - *Developing and flight-validating revolutionary technologies*
  - *Reducing development times and life cycle mission costs*
  - *Enabling highly autonomous spacecraft*
  - *Promoting nationwide teaming and coordination*

NMP ROLE

Flight Validation of Breakthrough Technologies to Benefit Future Earth Science Missions



Breakthrough technologies

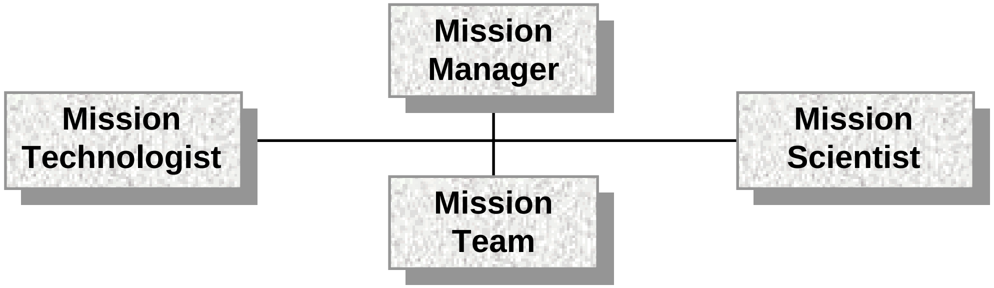
- Enable new capabilities to meet Earth Science needs
- Reduce costs of future missions

Flight validation

- Mitigates risks to first users
- Enables rapid technology infusion into future missions

NMP Mission Implementation

- ***Mission Team established in early definition***
- ***Selection process extends through Confirmation Review***
- ***NMP missions are NOT small science missions and cannot be treated as such -- inherently more risky***
- ***Keys to success:***
  - ***Resilient "Category" Architecture***
  - ***Comprehensive, aggressive risk management***
  - ***Adequate reserves in schedule and budget***
  - ***Critical role of mission technologist***
  - ***Management approach:***



Technology Transfer and Infusion

- *Validation Plans are executed for each assigned technology*
- *Each validation plan has two parts:*
  - *Technical*
  - *Science*
- *After flight validation, the Mission Technologist and Technology Provider prepare Technology Transfer documentation based on:*
  - *Basic design features and planned performance*
  - *Ground-based calibration and characterization*
  - *On-orbit technical and science validation*
  - *Operational experience*
  - *Likely applications*
  - *Technology Infusion opportunities*
- *NMP workshops, technology fairs, etc. are used to disseminate the Technology Transfer documentation*
- *NMP works closely with Earth and Space Science Program Offices to facilitate technology infusion into future science missions*

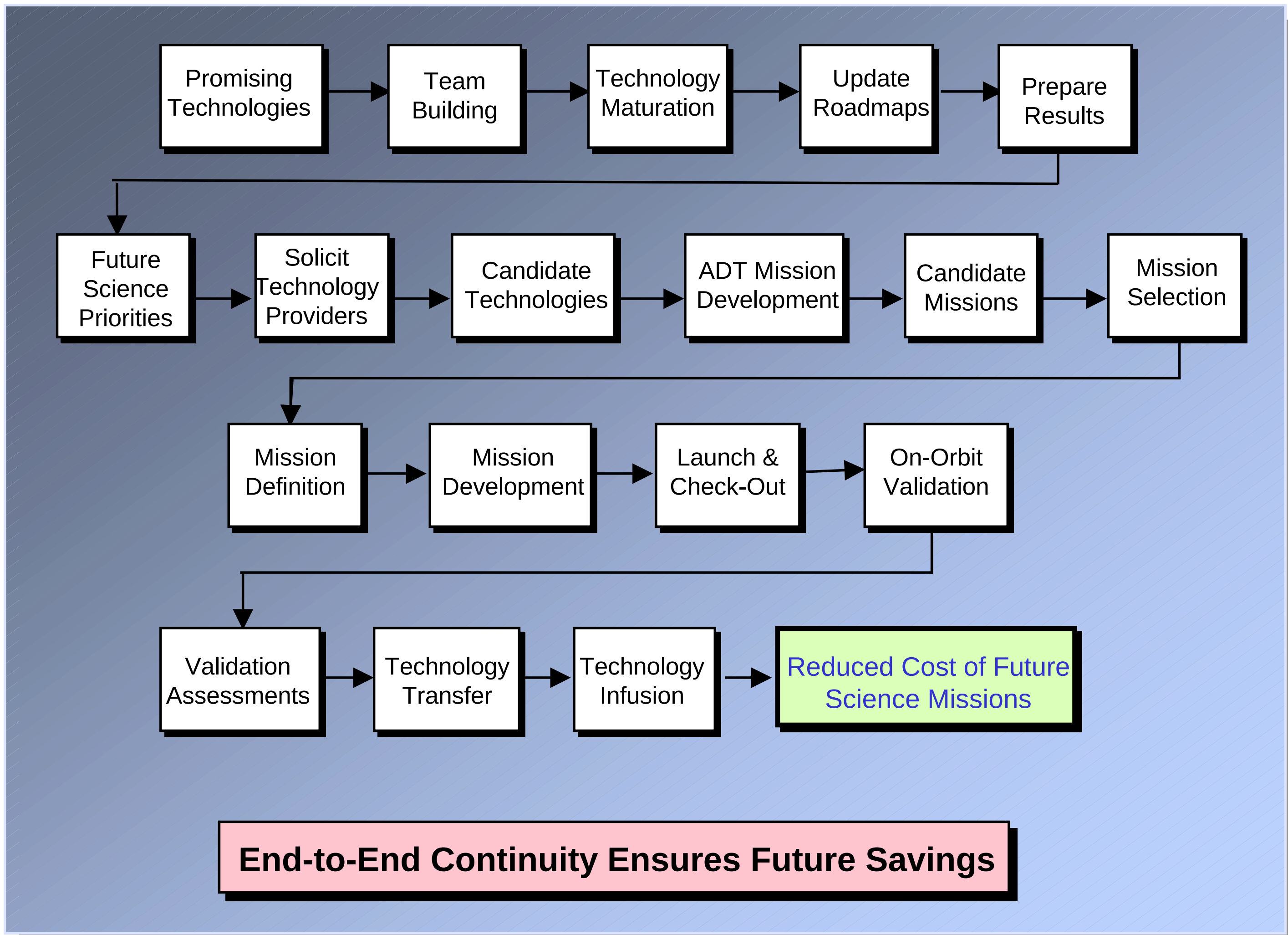
NMP Technology Evolution

SEEDING

SELECTING

DEVELOPING

VALIDATING



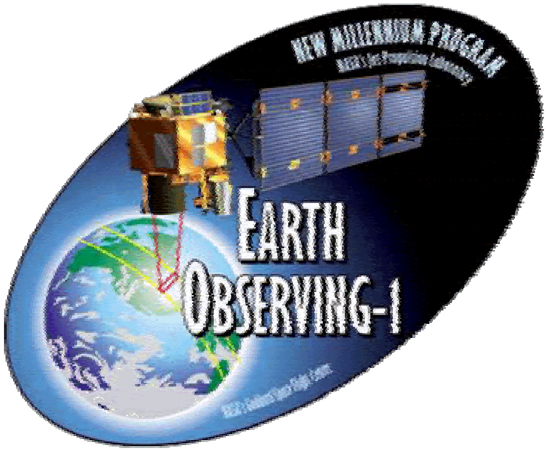
NMP Summary

- ***NMP provides the processes to:***
  - *Reduce the cost and enhance the performance of future missions*
  - *Leverage our investments in advanced technology*
  - *Encourage teaming within U.S. Aerospace industry*
- ***NMP provides the process to explore more effective use of emerging technologies to enable future missions***

<u>*Section 3*</u>

EO-1 Mission Overview

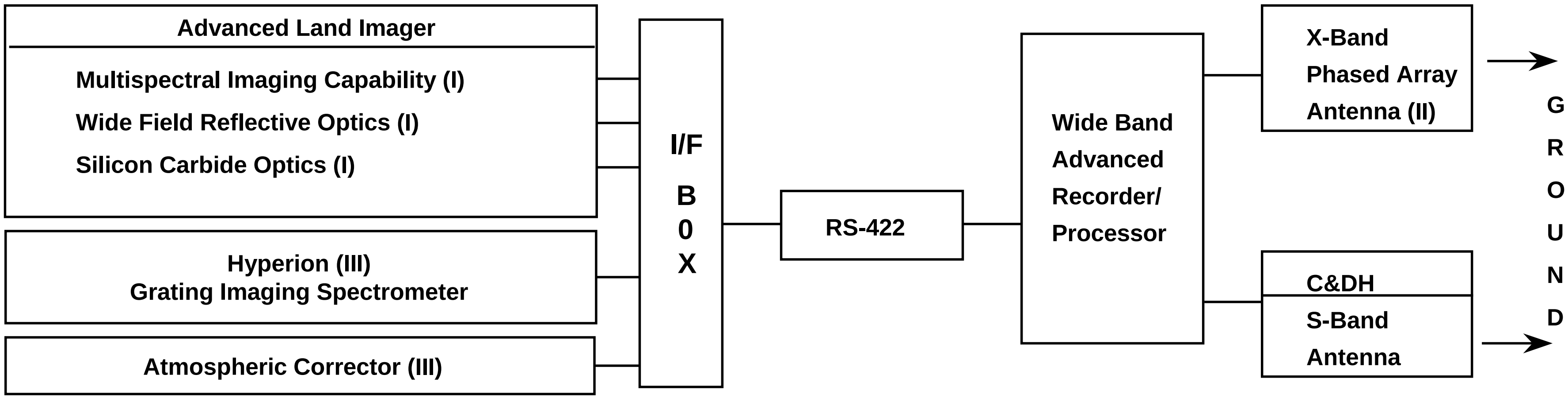
What is EO-1?

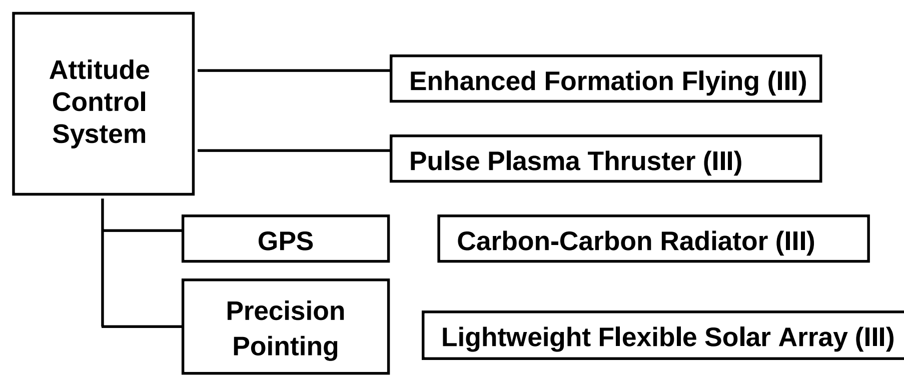


Visit our
Web Site @
http://eo1.gsfc.nasa.gov/

- ***Designed to flight validate breakthrough technologies applicable to Landsat follow-on missions***
- ***Specifically responsive to the Land Remote Sensing Policy Act of 1992 (Public Law 102-55) wherein NASA is charged to ensure Landsat data continuity through the use of advanced technology:***
  - ***Multispectral Imaging Capability to address traditional Landsat user community***
  - ***Hyperspectral Imaging Capability to address Landsat research-oriented community -- backward compatibility essential***
  - ***Calibration test bed to improve absolute radiometric accuracy***
  - ***Atmospheric correction to compensate for intervening atmosphere***

EO-1 Technologies





EO-1 TECHNOLOGIES

- *Multispectral Imaging Capability*
- *Wide Field Reflective Optics*
- *Silicon Carbide Optics*
- *Grating Imaging Spectrometer (HYPERION)*
- *Atmospheric Corrector (AC)*
- *X-Band Phased Array Antenna*
- *Enhanced Formation Flying (EFF)*
- *Pulse Plasma Thruster (PPT)*
- *Carbon-Carbon Radiator (CCR)*
- *Lightweight Flexible Solar Array*
- *Wideband Advanced Recorder / Processor (WARP)*
- *Global Positioning System (GPS)*
- *Precision Pointing*

NMP Technology Categories

CATEGORY I

- ***Essential Technology***
- ***Willing to restructure mission in order to fly it***
- ***If technology gets into trouble -- you fix it***
- ***Part of minimum mission***

CATEGORY II

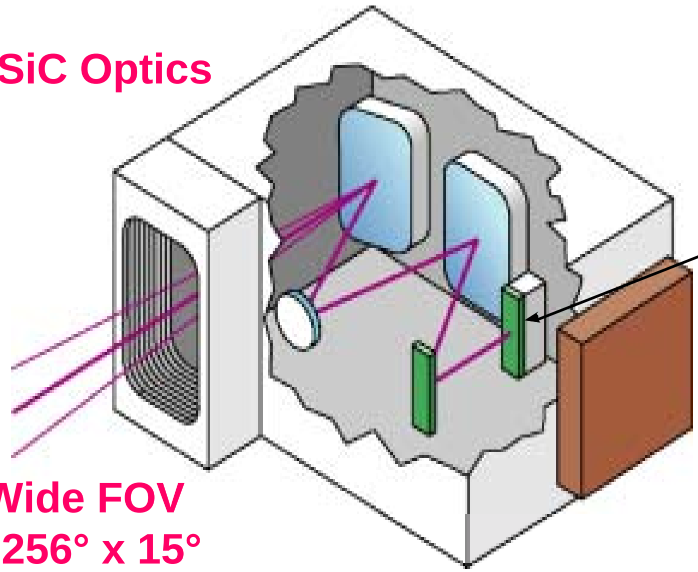
- ***Technology provides an essential mission function***
- ***A conventional approach is pre-planned***
- ***If technology gets into trouble -- you switch to the conventional approach***

CATEGORY III

- ***Technology exercises a flight opportunity***
- ***If technology gets into trouble -- you defer it to a later flight***

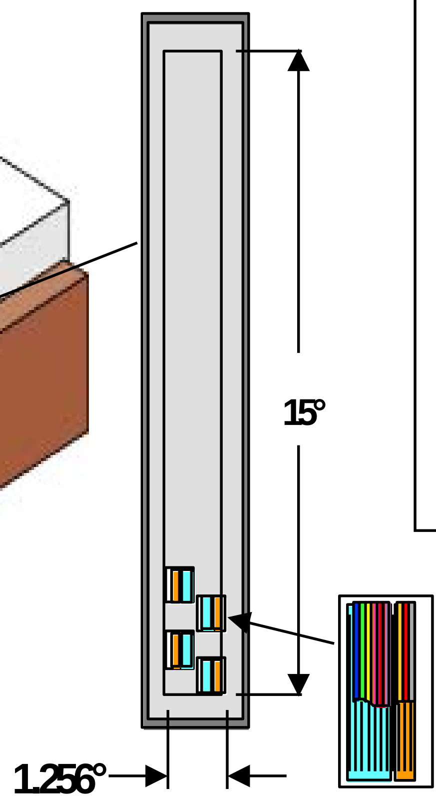
Advanced Land Imager (ALI)

SiC Optics

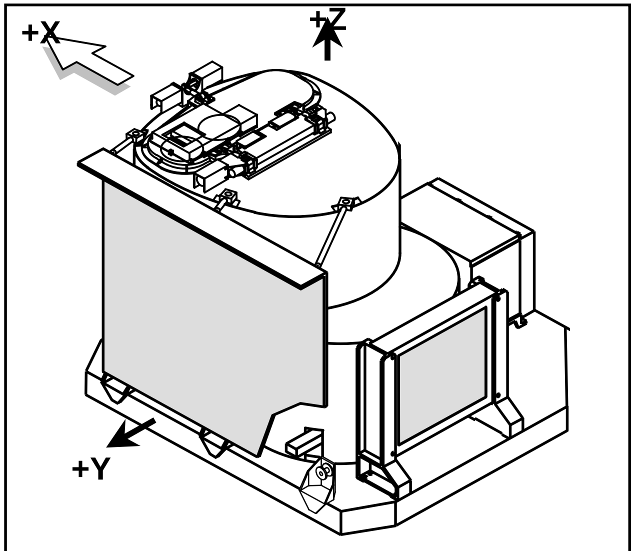


Wide FOV
1.256° x 15°

Main Focal Plane Assembly



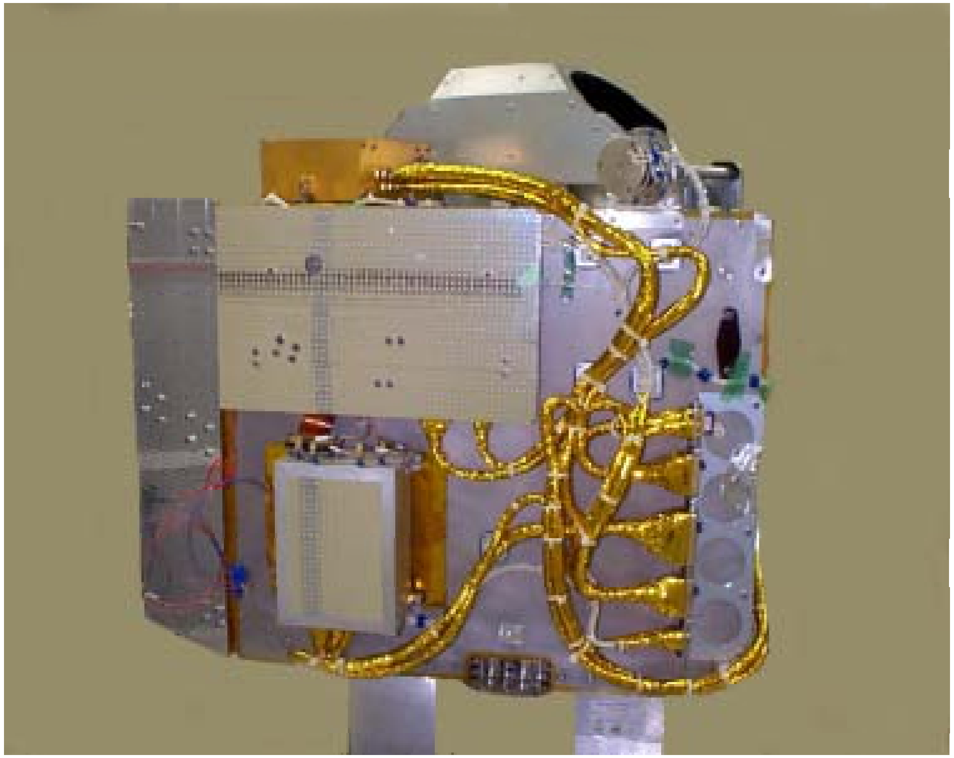
Multispectral/
Panchromatic
6 VNIR + 3 SWIR
220 K



ALI Without MLI

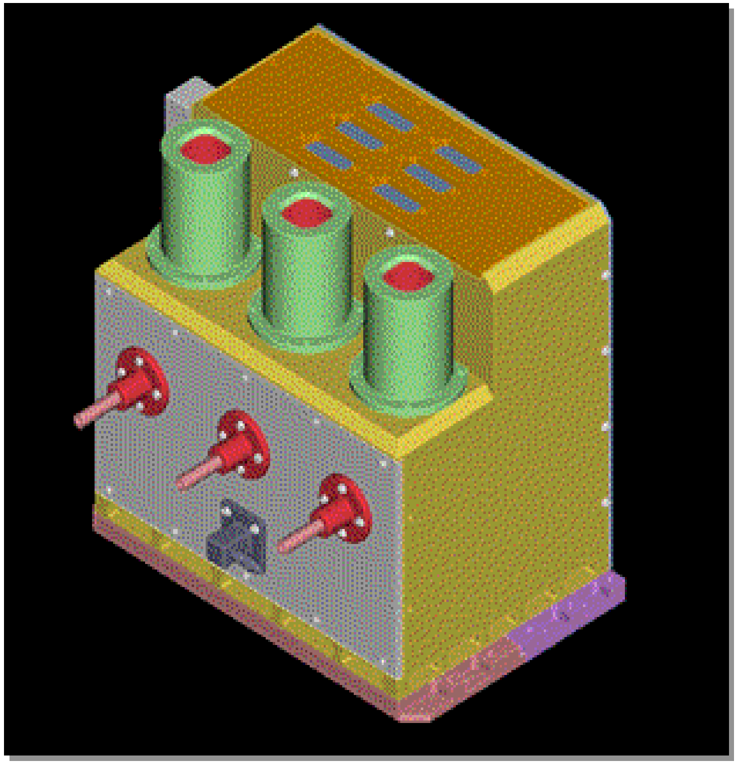
Band	Ground Sampling
Pan	10 m
MS	30 m

Hyperion Imaging Spectrometer



- ***Convex Grating spectrometers with CCD VNIR and HgCdTe SWIR detectors***
- ***30m spatial and 10nm spectral resolutions over 7.5km swath and 400-2500nm spectral range***
- ***Multiple calibration options: lamps, lunar, solar, ground imaging and laboratory***
- ***Hyperspectral Imaging Capability to address Earth Observation applications***

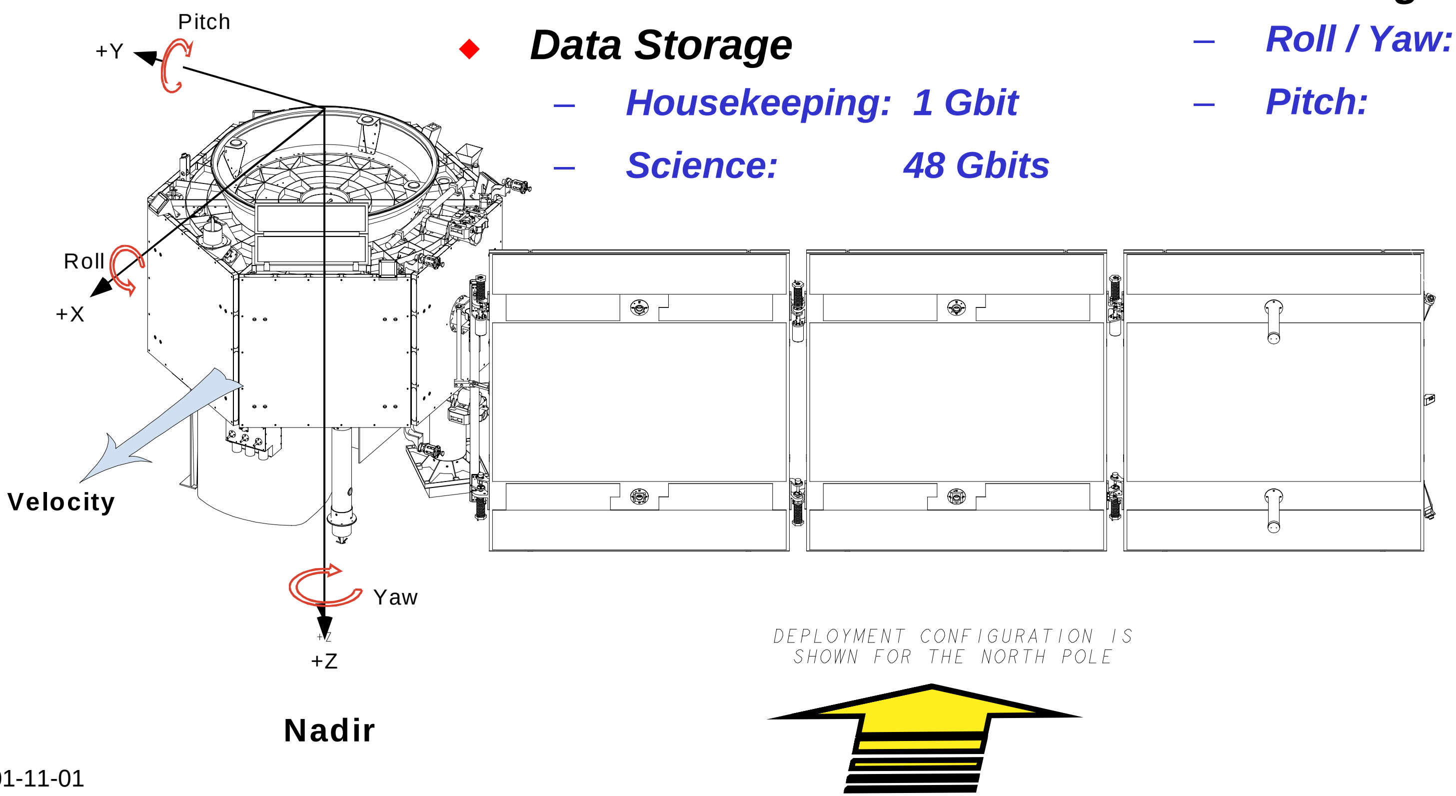
LEISA Atmospheric Corrector



- ***Correction of multispectral surface imagery for atmospheric variability (water and aerosols)***
- ***High spectral, moderate spatial resolution (250m), large swath (180km) hyperspectral imager using wedge filter technology***
- ***Spectral coverage of 0.89 - 1.6µm, bands selected for optimal correction of high spatial resolution images***

EO-1 Spacecraft

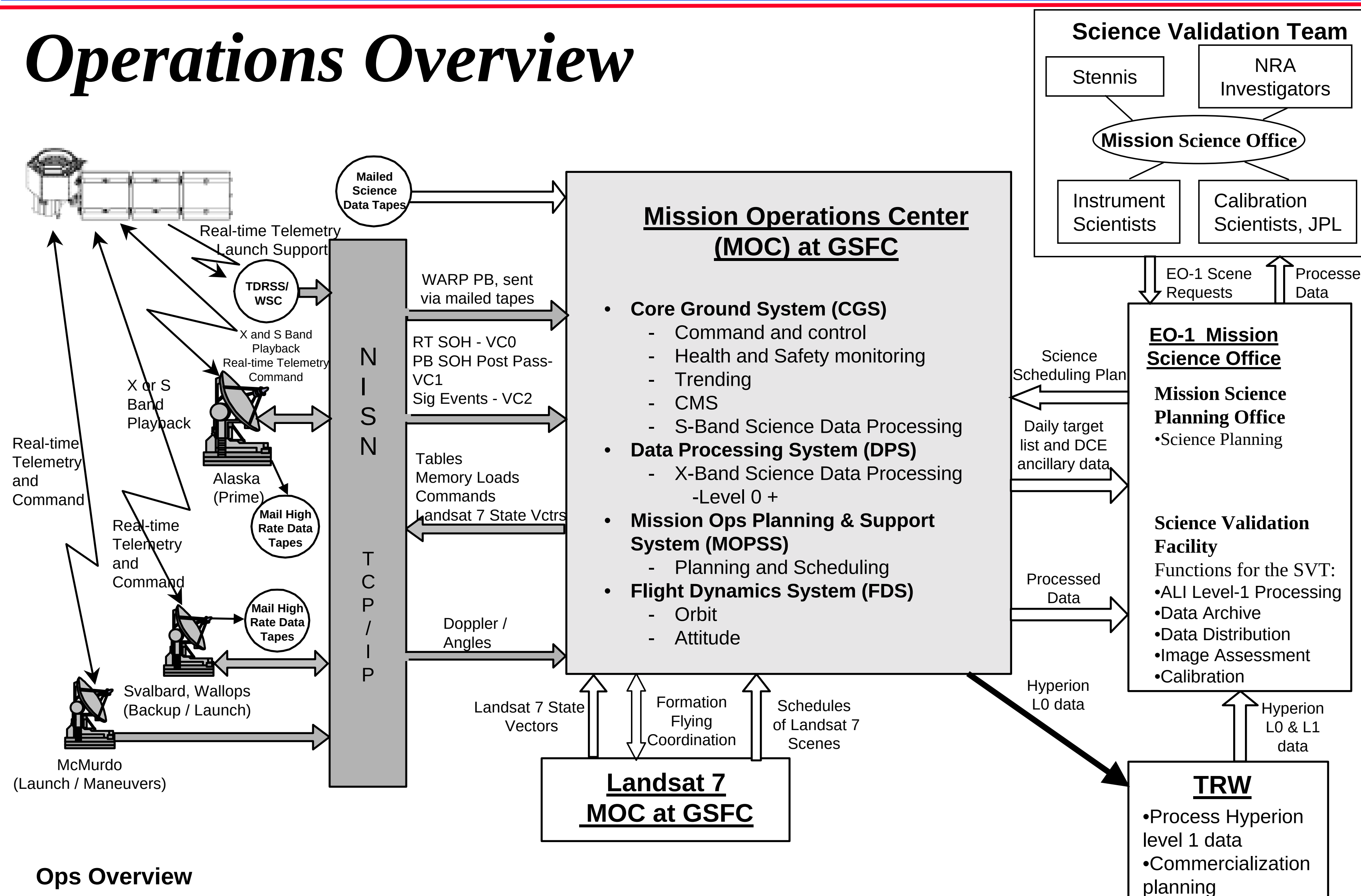
- **Power**
  - 315 Watts
  - 50 Ahr
  - Super NiCd
- **Data Storage**
  - Housekeeping: 1 Gbit
  - Science: 48 Gbits
- **Articulating Si Solar Array**
- **Mass**
  - 588 Kg
- **ALI Pointing**
  - Roll / Yaw: 0.022°
  - Pitch: 0.033°



Spacecraft Technologies

- *Wideband Advanced Recorder / Processor (WARP)*
- *X-Band Phased Array Antenna*
- *Enhanced Formation Flying*
- *Pulse Plasma Thruster*
- *Carbon-Carbon Radiator*
- *Lightweight Flexible Solar Array*
- *Global Positioning System*
- *Precision Pointing*

Operations Overview



Ground System Requirements Summary

Ground stations to receive, process, and route science and HK data to GSFC

- ***X-Band:* Receive 160 Gbits per day for the first 120 days and 80 Gbits per day at 105 Mbps thereafter**
  - *Record the received X-band data on hard media, mail to GSFC, and store raw data for 30 days*
- ***S-Band:* Receive data at selected rates up to 4 Mbps**
  - *Housekeeping data: Route selected virtual channels to GSFC in real time, record up to 200 Mbits of data each day, and FTP recorded data to GSFC within one hour. Store raw data for 30 days.*
  - *Backup science data (up to 10 Gbits per day): Process as with X-band.*
- ***Perform Level 0 processing on the science and HK telemetry***
  - *Fill holes, reorder science into band order*

Ground System Requirements Summary (continued)

GSFC to receive and process data sent from the ground station

- ***Process MS/PAN science data to provide at least 200 paired scene comparisons with Landsat-7***
- ***HYPERION Science Processing at TRW***
- ***Maintain an orbit of sufficient precision for scene comparisons***
  - ***Follow Landsat-7 Ground Track ± 3 km and ≈ 1 minute behind***
- ***Maintain the health and safety of the spacecraft***
- ***Validate and calibrate onboard orbit and attitude subsystems***
- ***Perform orbit maneuver control to enable formation flying***
- ***Provide mission planning and command management***
- ***Archive raw and processed data***

Operational Phases

- **Launch & Early Orbit**
  - ✓ Launch and the first several orbits, spacecraft checkout, and instrument turn-ons
  - ✓ Approximately 15 days (20 days to get to 1 minute behind Landsat)
  - ✓ 1 minute behind Landsat 7
- **Instrument Checkout**
  - ✓ Full instrument checkout
  - ✓ Approximately 60 days
- **Nominal Ops**
  - – Science Validation
  - – 10 months
- **End of Life**
  - – Deorbit burn for reentry within 25 years

Summary of Mission Overview

- ***The EO-1 mission is responsive to the 1992 Land Remote Sensing Act wherein NASA will use advanced technology to ensure Landsat data continuity***
- ***It will flight validate improvements in:***
  - *Multispectral imaging*
  - *Hyperspectral imaging*
  - *Calibration*
  - *Atmospheric Correction*
  - *Spacecraft technologies useful to remote sensing*
- ***The mission was successfully launched on November 21, 2000***
- ***Selected EO-1 imagery will be available soon at: http://eo1.gsfc.nasa.gov/miscPages/images.html***

Section 4

Technology Transfer and Infusion

Technology Transfer and Infusion

- ***The NMP sponsors technology validation missions that lower the cost and increase the performance of future missions by rapidly infusing newly-validated technologies***
- ***Technology transfer into new applications and infusion into future missions are therefore essential objectives of the NMP***
- ***This workshop is the first of several to facilitate the transfer and infusion of EO-1 technologies***
- ***Separate technology transfer documentation will be prepared for each technology***
- ***Infusion opportunities tend to be specific to each technology and vary considerably***
- ***All infusion discussions are treated confidentially***

Technology Transfer

- *Once the flight validations are completed, the EO-1 Mission Technologist completes the Technology Transfer documentation*
- *This consists of:*
  - *Description of the technology*
  - *Ground verification / validation*
  - *Technical validation on-orbit*
  - *Science validation on-orbit*
  - *Usage experiences both the ground and in space*
  - *Proposed applications*
  - *Technology infusion opportunities*
  - *Contact information*
- *Distribution of Technology Transfer Documentation:*
  - *Initially available on the EO-1 Web site*
  - *Workshops -- first in January 2001, second planned for August 2001*
  - *Conferences*
  - *Published papers*

Technology Infusion

- *Technology Infusion opportunities are described in the Technology Transfer Documentation*
- *They tend to vary from outright acquisition of the technology in the case of NASA-owned technologies to negotiated use in the case of commercially-owned technologies*
- *Technology infusion discussions are essentially follow-up activities to the distribution and presentation of the Technology Transfer documentation*
- *These discussions are held one-on-one with potential users and all are treated confidentially*
- *A specific Technology Infusion Plan is developed for those interested in incorporating a technology into a future mission*
- *Where appropriate, NASA is willing to provide limited funding to facilitate the infusion process*
- *The Mission Technologist is the contact for this process*
  - *Nick Speciale at 301-286-8704*

Technology Workshops

- ***First workshop in January 2001 with emphasis on the three EO-1 instruments:***
  - *Advanced Land Imager*
  - *Hyperion*
  - *Atmospheric Corrector*
- ***Second, longer workshop planned for August 2001:***
  - *To discuss preliminary flight-validation results and usage experiences with the instruments*
  - *To discuss spacecraft technologies in the same detail as instruments*
  - *To review available Technology Transfer Documentation*
  - *To begin development and implementation of individual Technology Infusion Plans*
  - *To ponder the feasibility of an Extended Mission to consider data sharing arrangements and tasking opportunities to interested parties*

Technology Workshops *(continued)*

- ***Third workshop planned for March 2002:***
  - *To present final results of flight-validations*
  - *To present Technology Transfer Documentation*
  - *To review status of existing Technology Infusion Plans*
  - *To review status of Extended Mission if approved for FY'02*
  - *To push to complete development of Technology Infusion Plans by end of FY'02*
- ***EO-1 activities conclude at the end of FY'02:***
  - *Technology Transfer Documentation subsequently available through NMP*
  - *Subsequent Technology Infusion activities managed by NMP*
  - *EO-1 Lessons Learned completed by end of FY'02 and available through NMP*

Section 5

Advanced Land Imager

. . . Donald E. Lencioni
ALI Instrument Scientist
MIT Lincoln Laboratory

. . . Constantine J. Digenis
ALI Program Manager
MIT Lincoln Laboratory

Topics of Discussion

- ***ALI Overview***
- ***Design and performance***
- ***Pre-launch Calibration and Characterization***
- ***Application to future Landsat instruments --- technology transfer***
- ***On-orbit performance assessment***
- ***Summary***

EO-1 Advanced Land Imager Overview

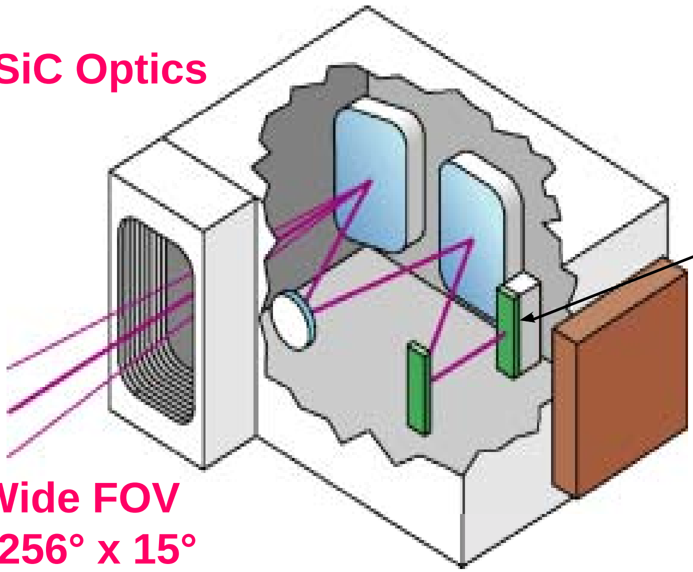
- *Primary instrument on the first Earth Observing Mission (EO-1) of NASA's New Millennium Program (NMP)*
- *Objectives are to flight validate key technologies*
  - *Data continuity, advanced capability and cost reduction for future Landsat instruments*
  - *Innovative approaches to future land imaging*
- *The ALI instrument was designed and developed by MIT Lincoln Laboratory with NMP instrument team members*
  - *Raytheon SBRS for the focal plane system*
  - *SSG Inc. for the optical system*

Driving Requirements

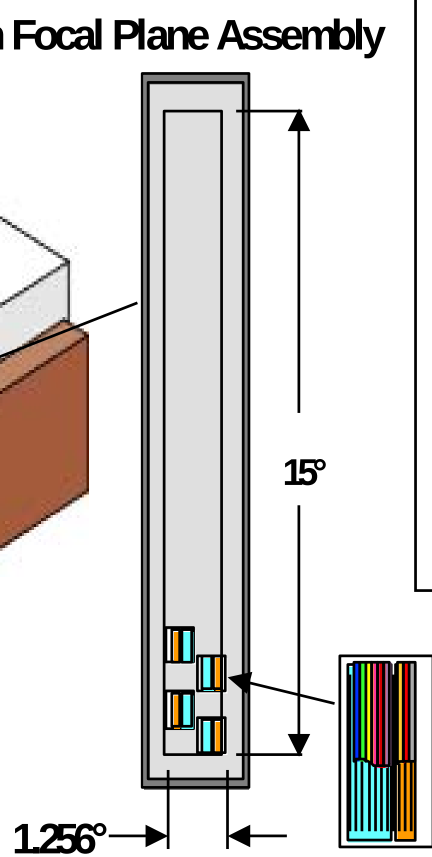
- *Instrument architecture developed from technologies represented on the NMP IPDT*
- *Flight validation of technologies required to significantly reduce the risk for future missions*
- *Flight data must be amenable to science validation*
- *Measurement requirements were developed*
  - *From the bottom up by the IPDT*
  - *In collaboration with the earth science community*
- *Design must be scaleable to a full-up instrument*

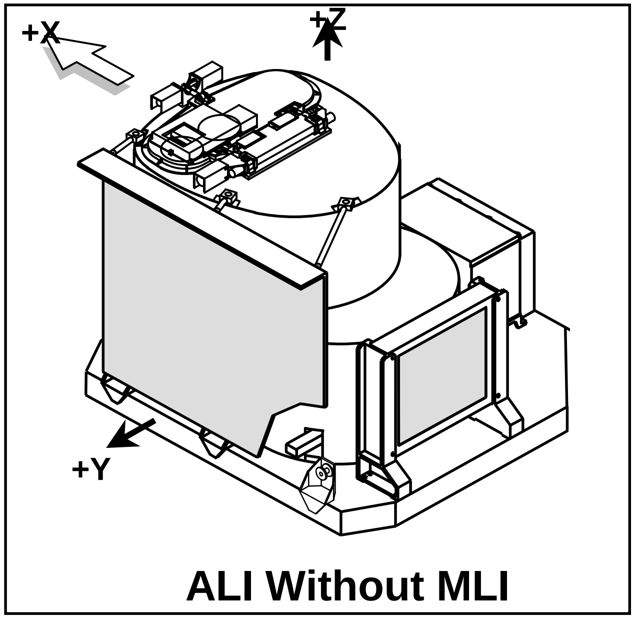
Advanced Land Imager (ALI)

SiC Optics



Wide FOV
1.256° x 15°



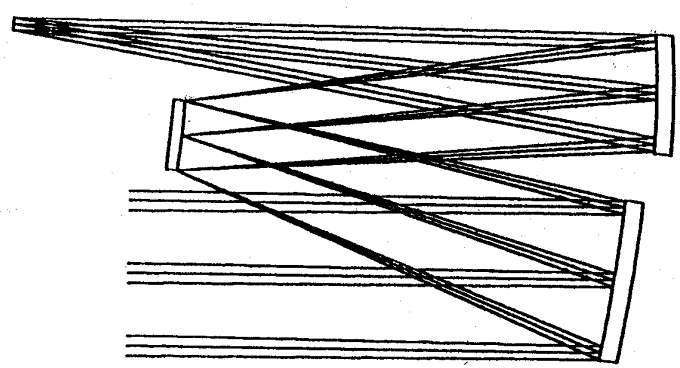


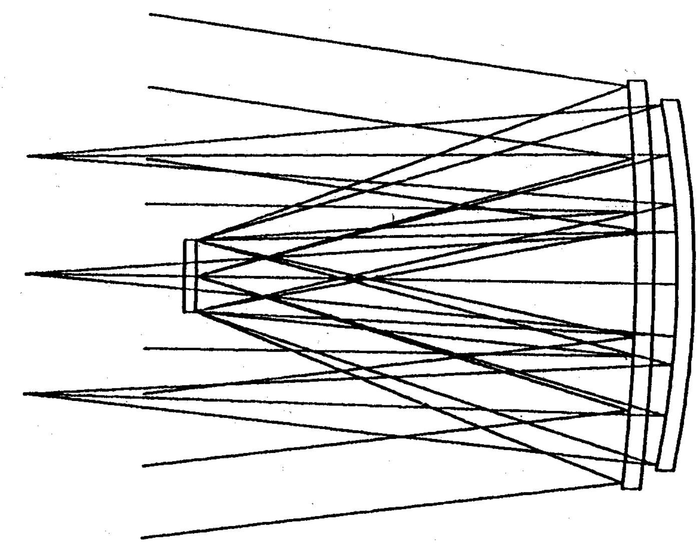
Multispectral
Panchromatic +
6 VNIR + 3 SWIR
220 K

Band	Ground Sampling
Pan	10 m
MS	30 m

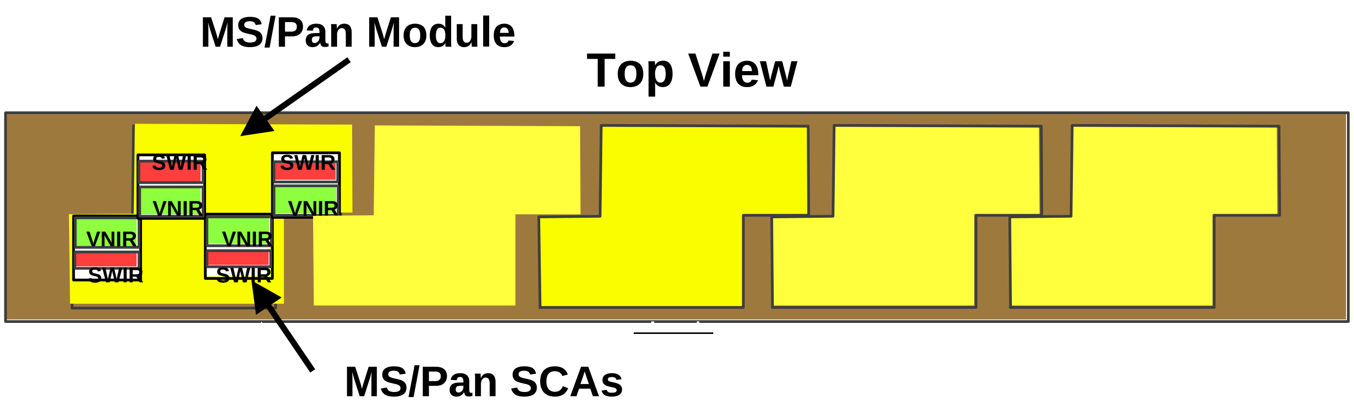
ALI Optical Design Form

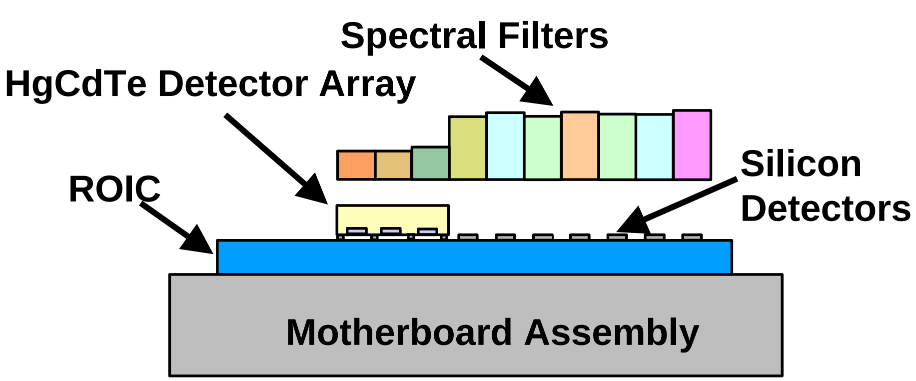
- All reflective Cooke Triplet
  - –Aspheric primary
  - –Ellipsoidal secondary
  - –Spherical tertiary
- Aperture stop on secondary mirror
- Non-relayed design
- Near telecentric
- FOV = 1.256 x 15 degrees





Main Focal Plane Assembly

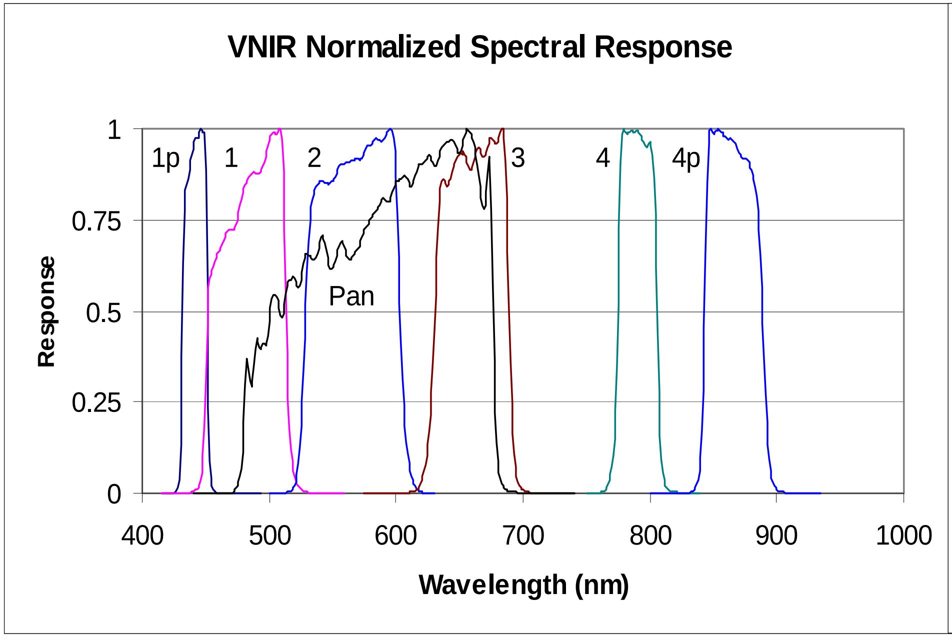


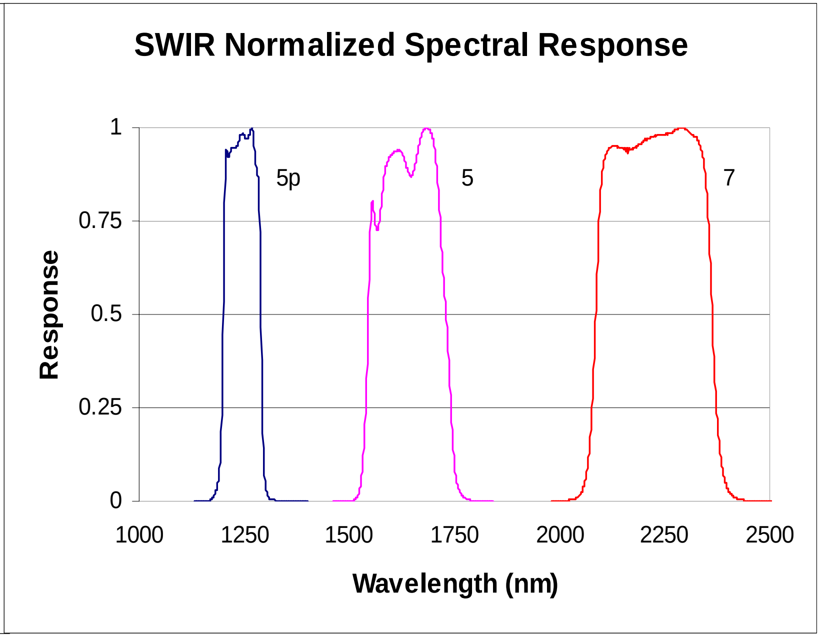


MS/Pan SCA

MS : Multispectral
Pan : Panchromatic
ROIC : Read-out Integrated Circuit
SCA : Sensor Chip Assembly
SWIR : Short Wave Infrared
VNIR : Visible Near Infrared

ALI Spectral Response Functions



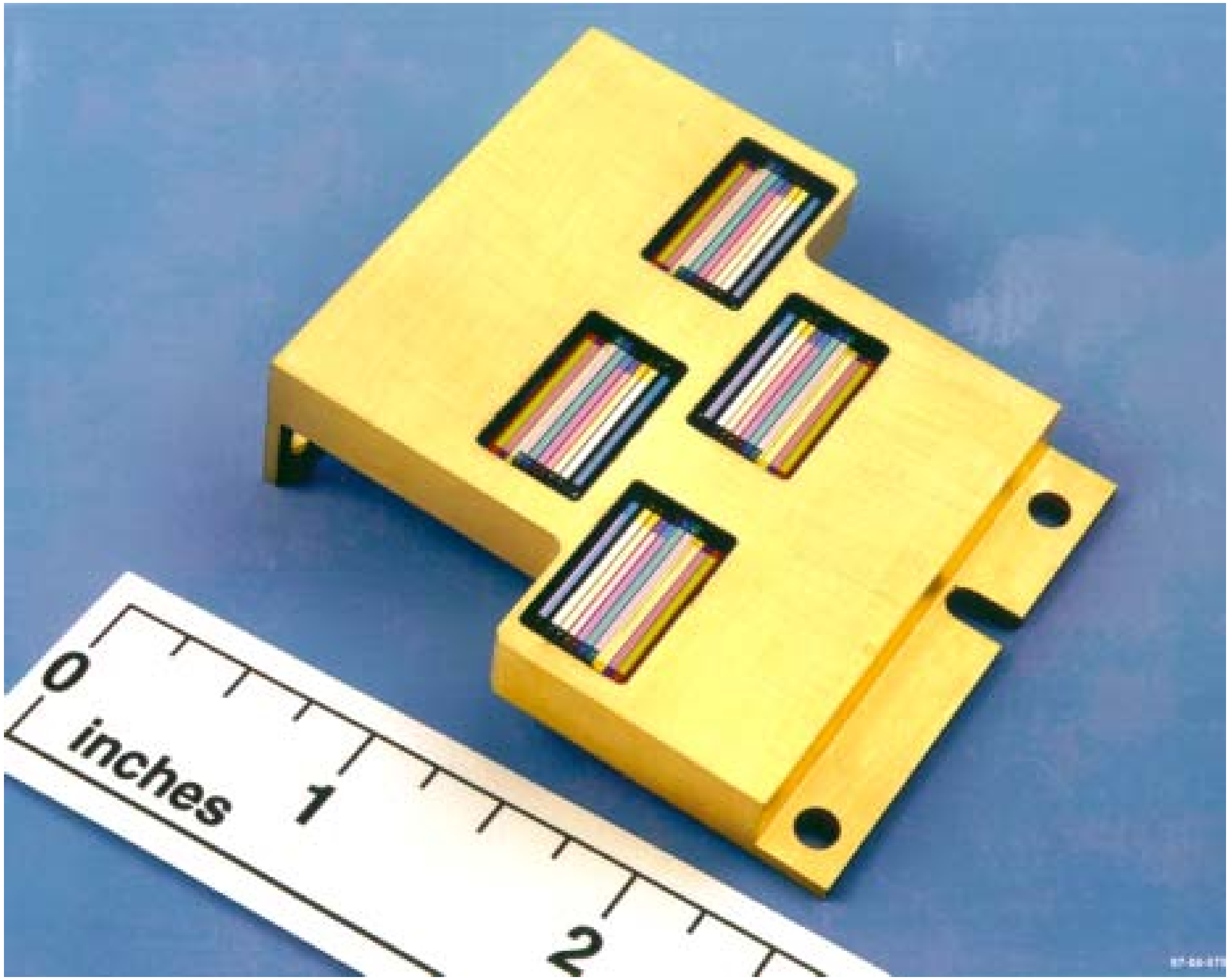


EO-1 ALI MS/PAN

Spectral and Spatial Coverage

Band	Wavelength(μm)	Detector Type	GSD (m)	# of Detectors
Pan	0.480-0.690	Si Photodiode	10	3840
MS-1'	0.433-0.453	Si Photodiode	30	1280 Per Band
MS-1	0.450-0.515			
MS-2	0.525-0.605			
MS-3	0.630-0.690			
MS-4	0.775-0.805			
MS-4'	0.845-0.890			
MS-5'	1.200-1.300	PV HgCdTe	30	1280 Per Band
MS-5	1.550-1.750			
MS-7	2.080-2.350			

MS/PAN Flight Module




MAIN FOCAL PLANE ASSEMBLY, EO-1

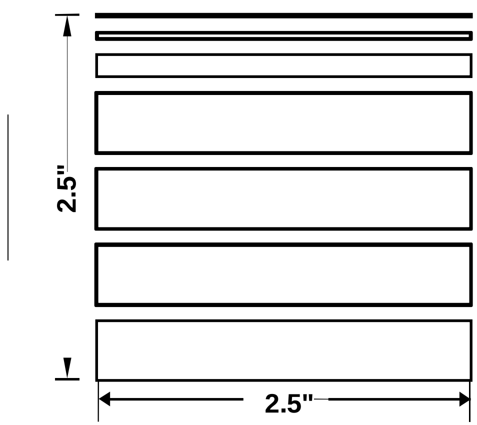
Partially Assembled Flight ALI

Telescope features

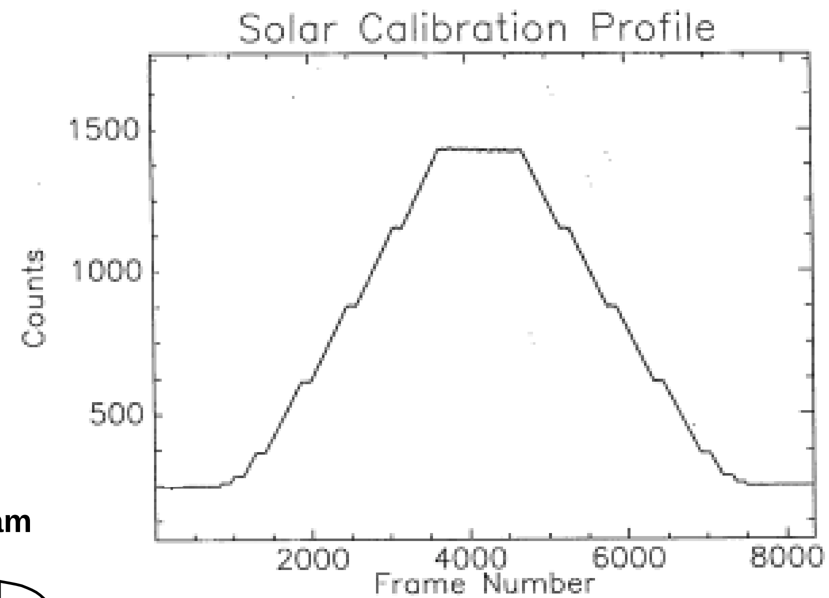
- 12.5 cm entrance pupil
- 15° x 1.26° field-of-view
- Telecentric, f/7.5 design
- Unobscured, reflective optics
- Silicon carbide mirrors
- Wavefront error = 0.11 λ RMS @ 633 nm

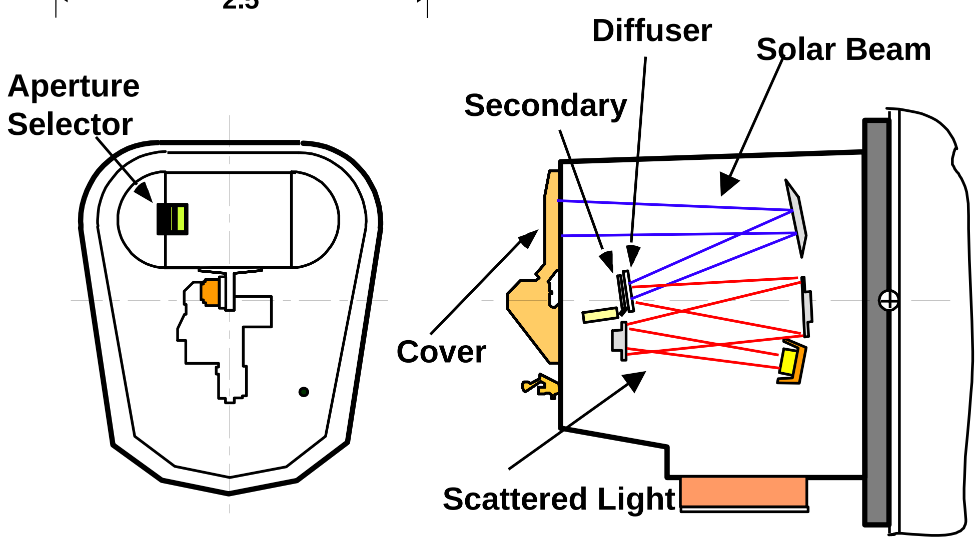
Installation of ALI into Thermal Vacuum Chamber

Solar Calibration



Signal Level	Cumulative Signal
1%	1%
2%	3%
7%	10%
20%	30%
20%	50%
20%	70%
20%	90%



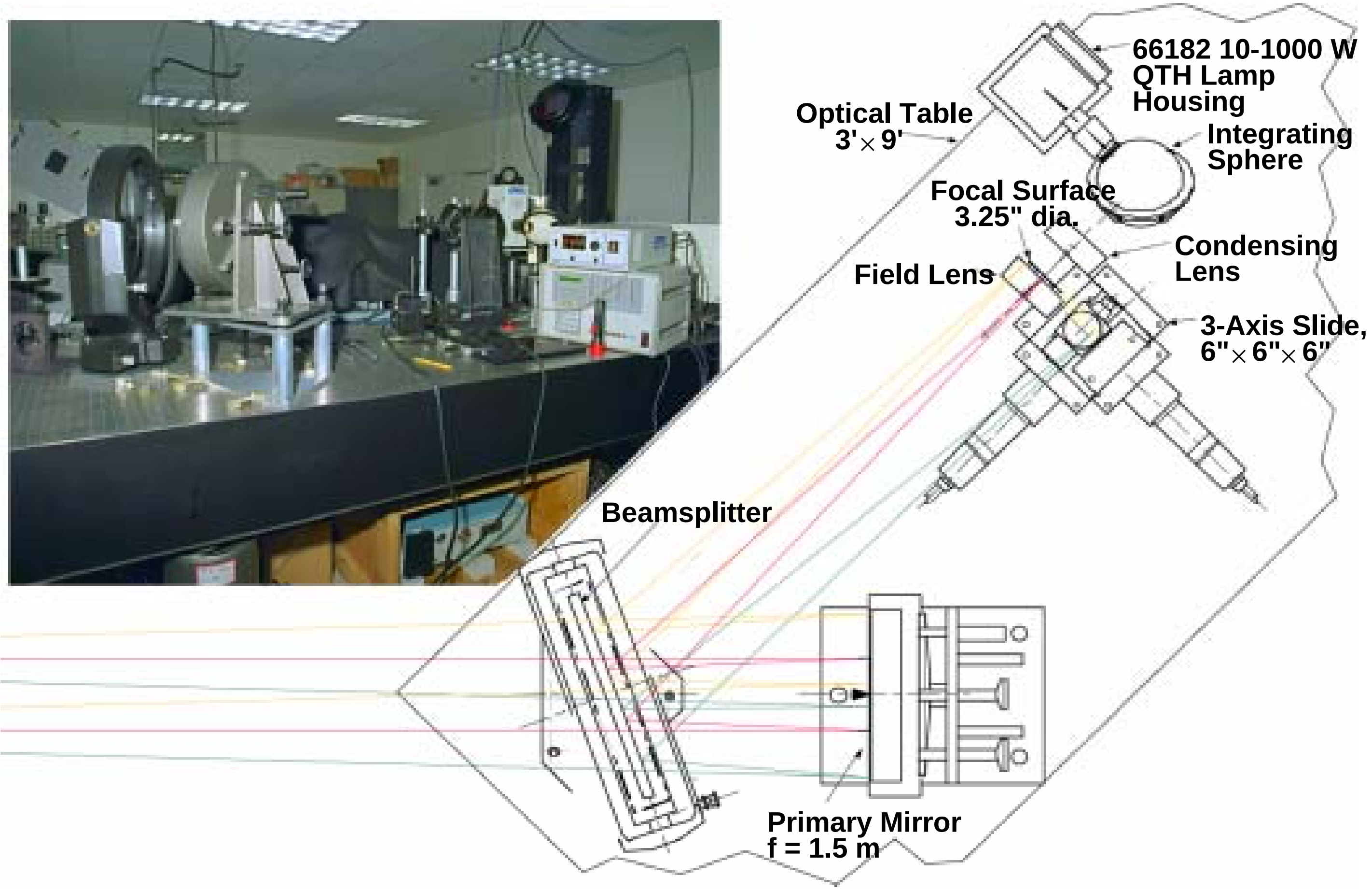


ALI Calibration Matrix

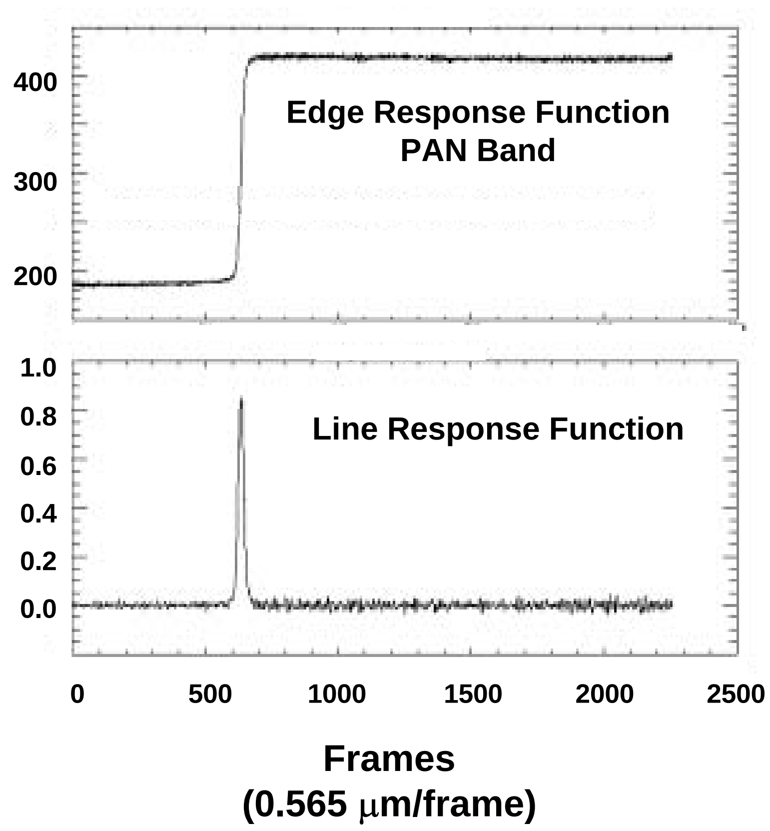
	Spectral Response Function	Response Coefficient	Zero Signal Offset	Pixel Angular Position	Modulation Transfer Function
Component Tests and Analysis	●	○	○	—	○
Subsystem Tests: Telescope and MS/Pan	○	○	○	○	○
Instrument-Level Laboratory Tests	●	●	○	●	●
On-Orbit Measurements:					
Solar Calibration	—	●	—	—	—
Dark Current	—	—	●	—	—
Int. Reference Lamps	—	○	—	—	—
Lunar Scans	—	○	○	—	○
Earth Scenes	—	○	—	○	○

● Primary Measurement ○ Secondary Measurement

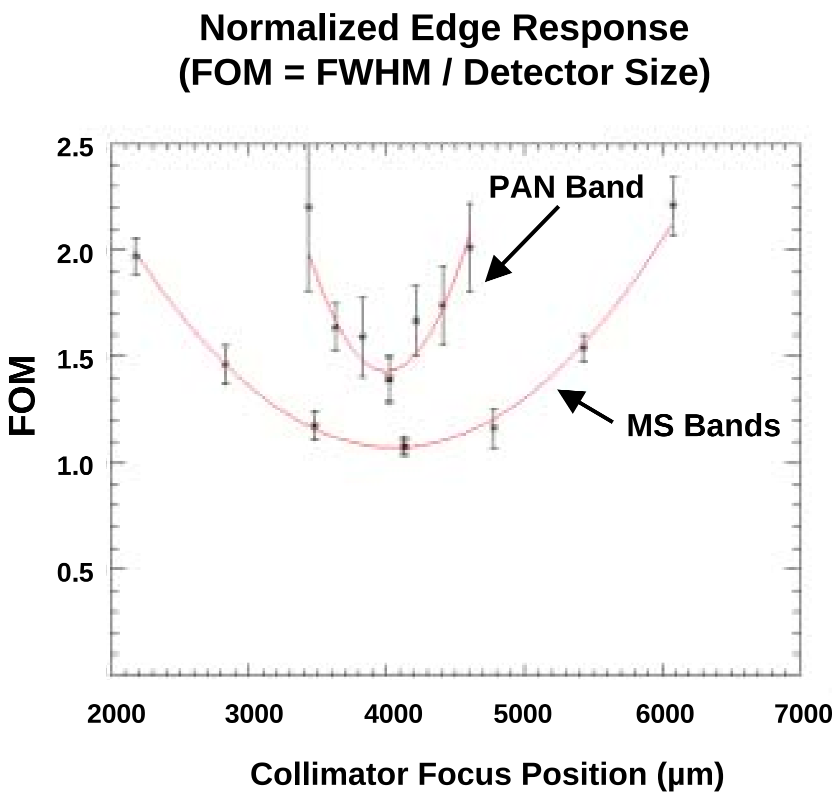
Imaging Test Optics



Focus Test



400
300
200
Edge Response Function
PAN Band
1.0
0.8
0.6
0.4
0.2
0.0
Line Response Function
0
500
1000
1500
2000
2500
Frames
(0.565 μm/frame)



Normalized Edge Response
(FOM = FWHM / Detector Size)
2.5
2.0
1.5
1.0
0.5
FOM
PAN Band
MS Bands
2000
3000
4000
5000
6000
7000
Collimator Focus Position (μm)

MTF Performance

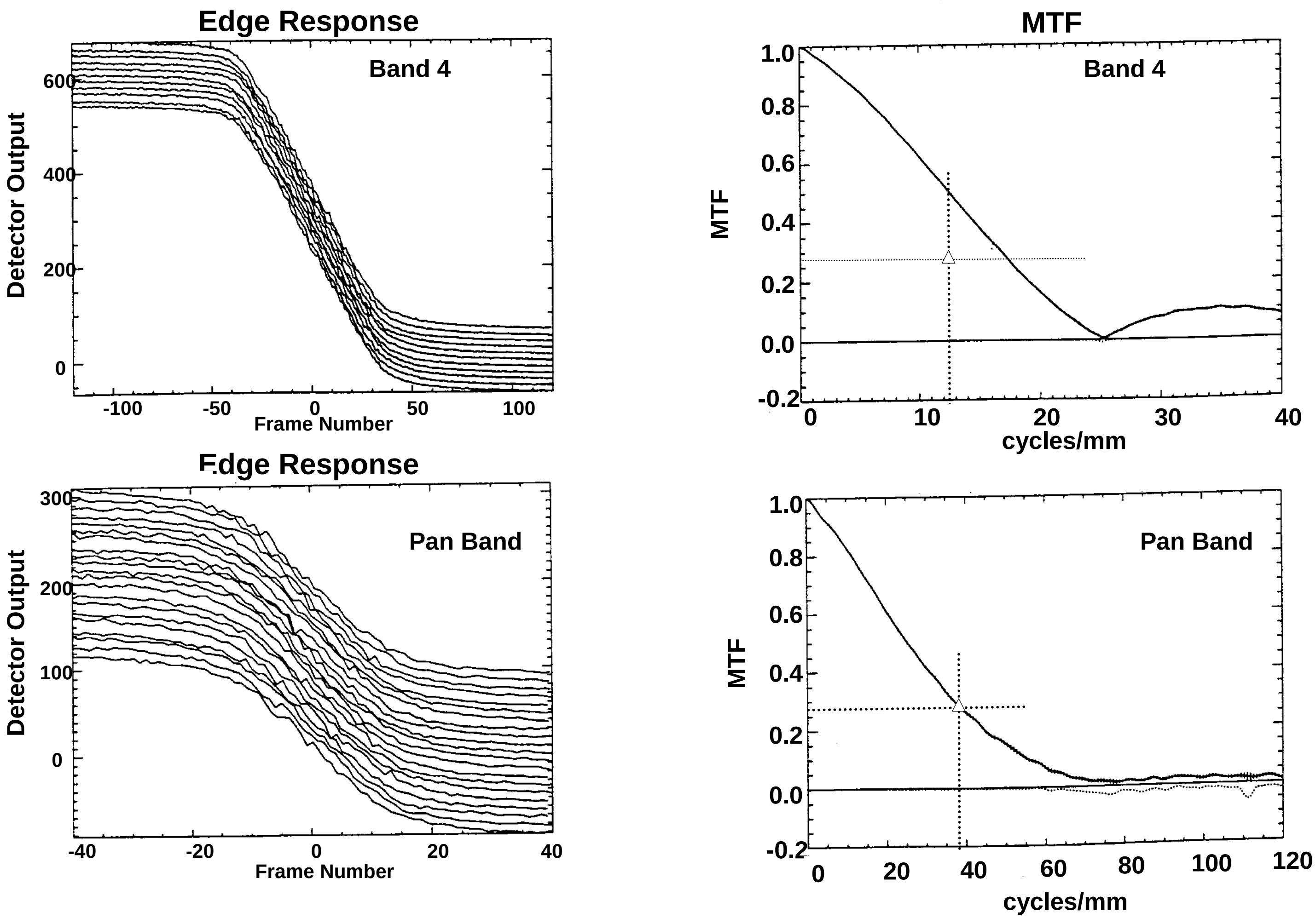
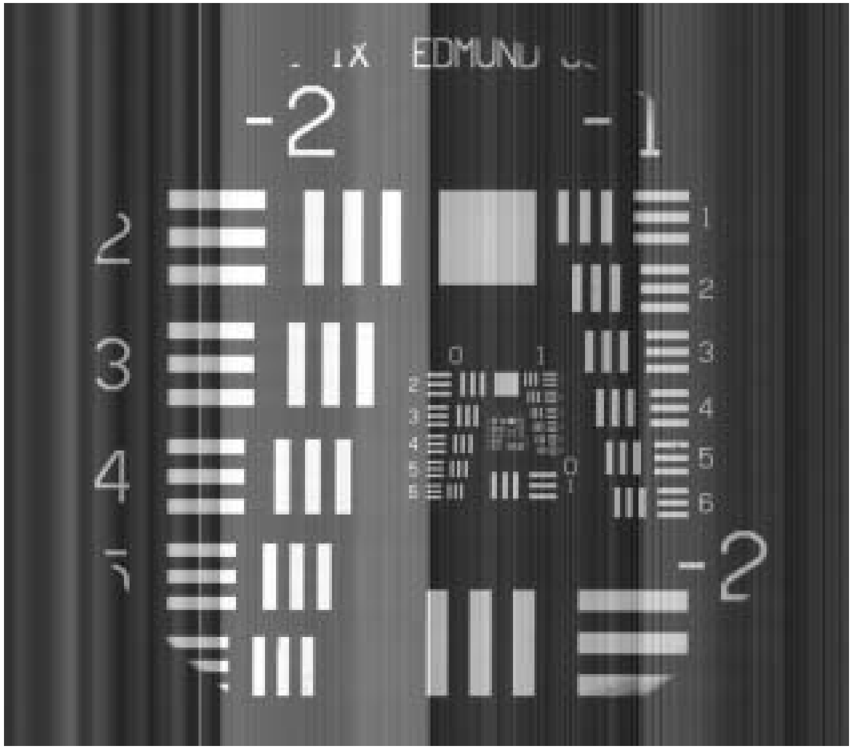
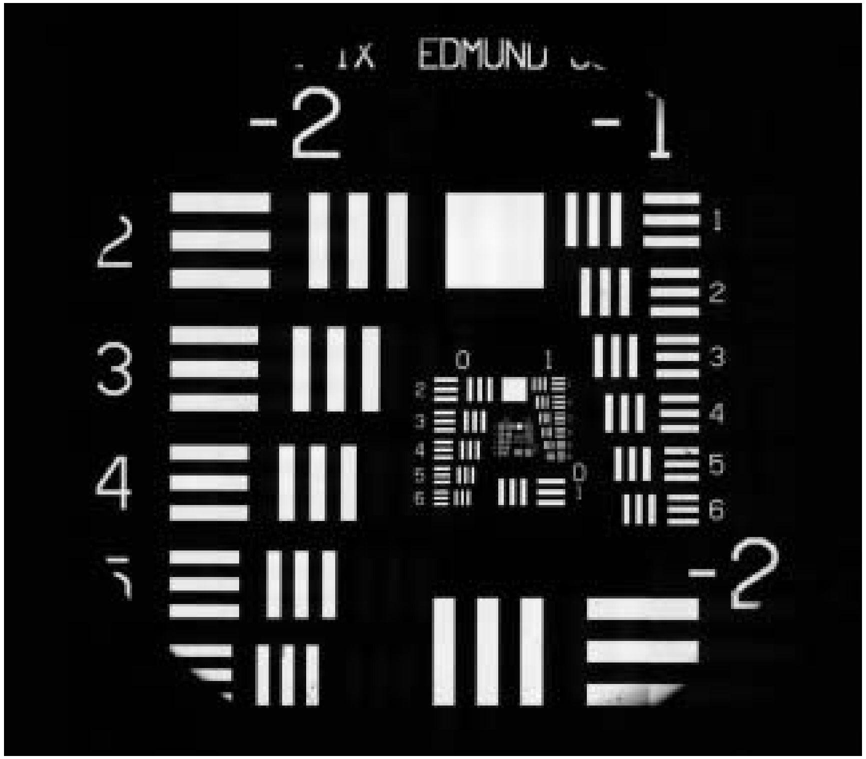


Image Reconstruction and Calibration

MS Band 1

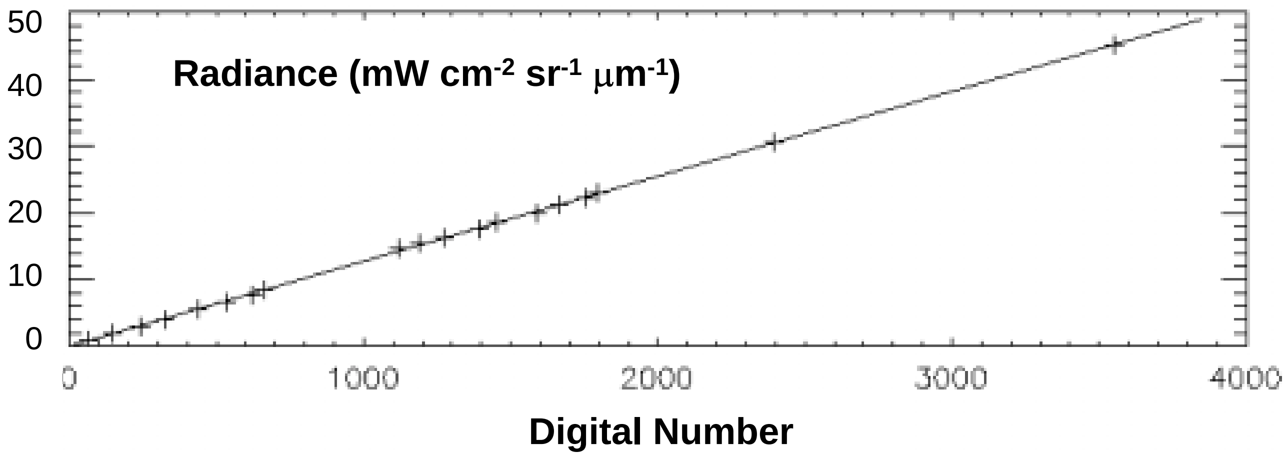


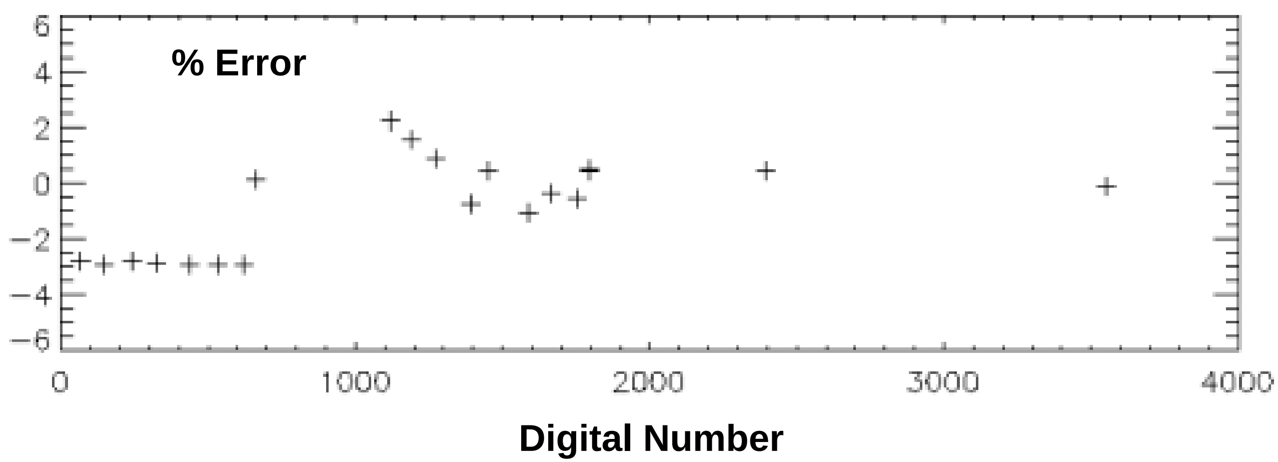
Reconstructed Raw Image



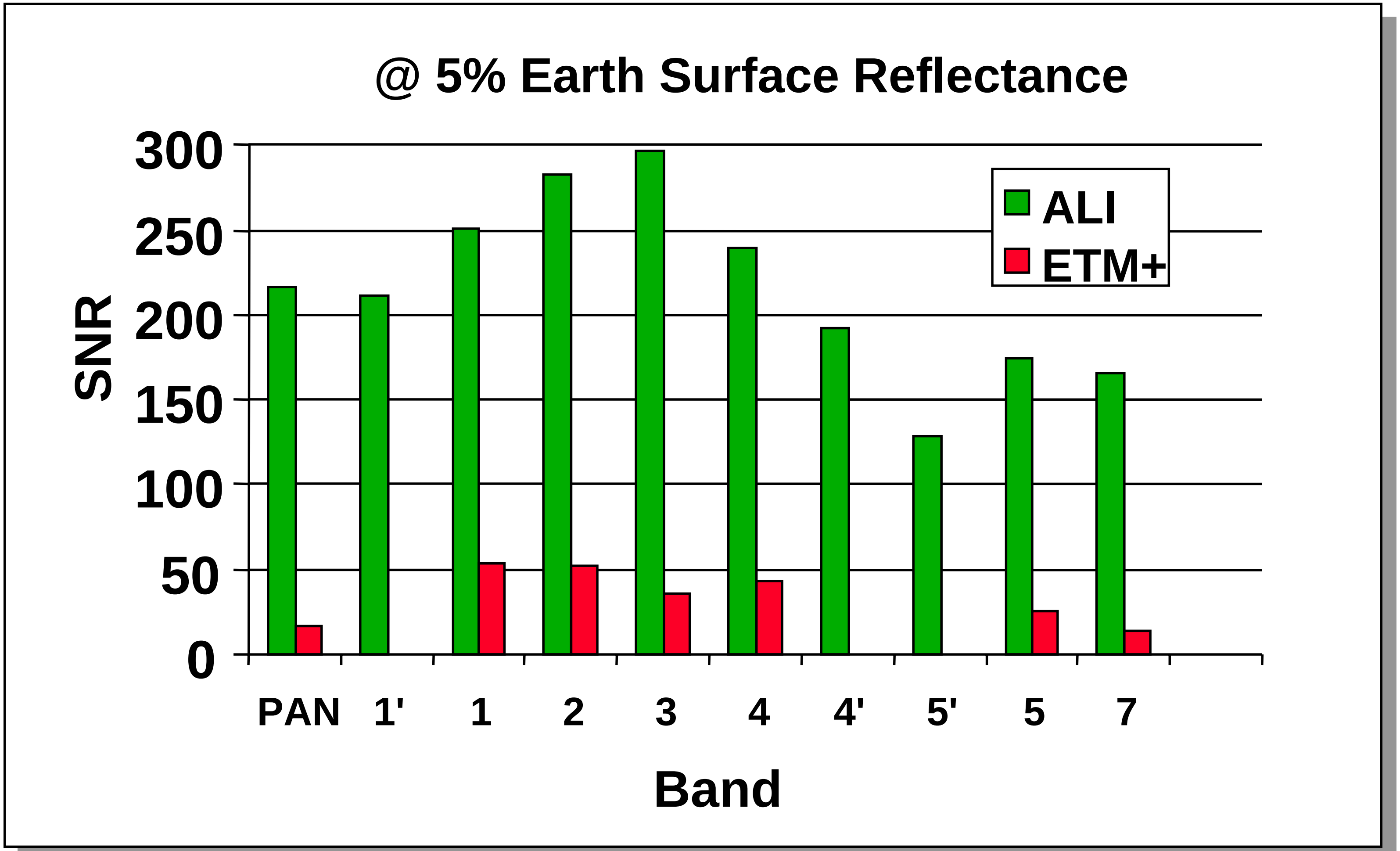
"Calibrated" Image

ALI Dynamic Range and Linearity





ALI SNR Performance



Growth Path to Advanced Instrument

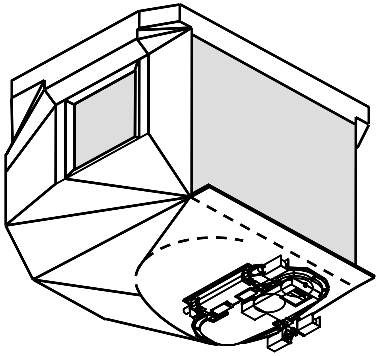
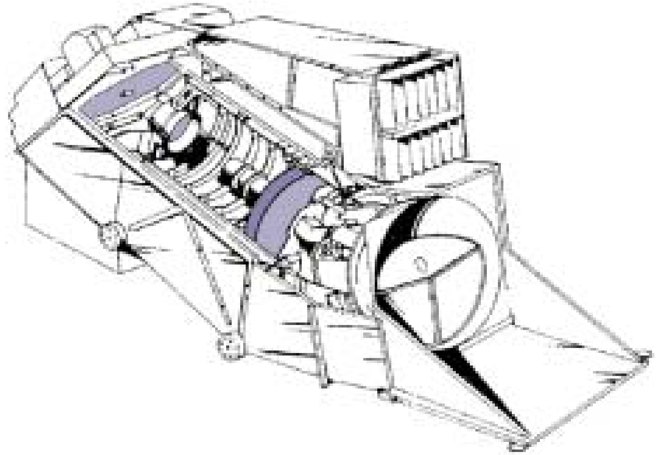
Populate focal plane with 5 MS/PAN modules

- Full 185 km wide field-of-view
- Main Focal Plane bench designed for 5 modules

Changes required to accommodate full MS/PAN coverage

Resource	*ALI*	*Advanced Landsat*
Data Ports	1	5
Data Rate	102.4 Mb/s	512 Mb/s
FPE Power	~ 15 Watts	~ 50 Watts
FPA Size	30.7 x 6.6 x 5.2 cm	30.7 x 6.6 x 5.2 cm

Land Imaging Instrument Comparison

ALI - Concept for Future Landsat Instrument		Enhanced Thematic Mapper (ETM+)
		
100	Mass (kg)	425
100	Power (W)	545
$70 \times 75 \times 75$	Size (cm)	$196 \times 114 \times 66$
7, 3, 0	VNIR, SWIR, LWIR Bands	5, 2, 1
10, 30	Pan, MS Resolution (m)	15, 30
4-10	Relative SNR	1

296268-7P

ALI Technology Transfer

- ***Objectives***
  - *Reduce cost and improve data quality for the LDCM*
  - *Exploit NASA's investment in the ALI technologies*
  - *Utilize Lincoln Laboratory's unique ALI expertise*
- ***Methods***
  - *Publications, reports, and documentation*
  - *NASA-sponsored workshops at Lincoln Laboratory*
  - *Technical support of an industry/government sensor development*
  - *Characterization and calibration of sensors at Lincoln Laboratory*
  - *Sensor integration and test by Lincoln Laboratory*
- ***Funding for MIT/Lincoln Laboratory (an FFRDC)***
  - *Directly from NASA or other government agency*
  - *Cooperative Research and Development Agreement with industry developer*

Summary

- ***The Advanced Land Imager is the primary instrument on the first Earth Observing Mission (EO-1) of NASA's New Millennium Program (NMP)***
- ***The ALI has undergone extensive pre-launch calibration and characterization and has demonstrated excellent performance***
- ***The EO-1 mission is now in progress and should successfully flight-validate the NMP technologies***
- ***These technologies provide a path for lower cost, higher performance, future Landsat instruments***
- ***MIT Lincoln Laboratory is interested in helping NASA transfer the ALI technology for application to future Landsat missions***

On-Orbit Performance Assessment

- ***Preliminary flight data and status***
- ***On-orbit performance assessment plan***
- ***Summary***

ALI Performance in Space

- ***ALI was turned on on November 25, 2000 (Day 5)***
- ***Launch latches were released and a series of comprehensive tests were conducted showing nominal instrument performance***
  - *The temperature control has been excellent*
- ***Obtained four earth scenes with the spacecraft pointing to nadir, i.e., the active part of ALI covering a swath 55 to 92 km east of the S/C ground track***
  - *Alaska, north-east of Anchorage*
  - *East Antarctica*
  - *Marshall Islands*
  - *North-central Australia*

Mission Operations

- ***The first earth scene with all instruments operating simultaneously was obtained on December 1, 2000***
- ***On December 15, 2000, EO-1 achieved its intended position, 1 minute behind Landsat 7***
- ***On December 21, 2000, EO-1 began to point towards the desired target within the Landsat swath. Until then, most of the recorded scenes represented targets of opportunity with the S/C in a nadir pointing mode***
- ***Comparison of ALI and Landsat scenes has not yet begun***
- ***The number of scenes per day has gradually increased from two to six. Eight is the planned maximum in the first four months.***
  - ***Four scenes per day will be acquired in the remainder of the first year***
  - ***No firm plans yet for the remainder of life (EO-1 has 5 years worth of consumables)***

Focal Plane Contamination

- *Ground testing had revealed fine droplets forming on the cold focal plane after several days at –53 C. They boil off between –20 C and –10 C*
- *ALI is equipped with enough heaters to raise the focal plane temperature to –3 C which has been effective in evaporating the unknown contaminant*
  - *Bake-outs on-orbit were planned every two weeks*
- *In space, it was noted that the contaminant accumulation is more severe and occurs faster than on the ground. The bake-out is still effective in boiling off the contaminant(s).*
  - *Bake-outs will be conducted weekly and the performance will continue to be monitored closely*

First ALI Image: Sutton, AK

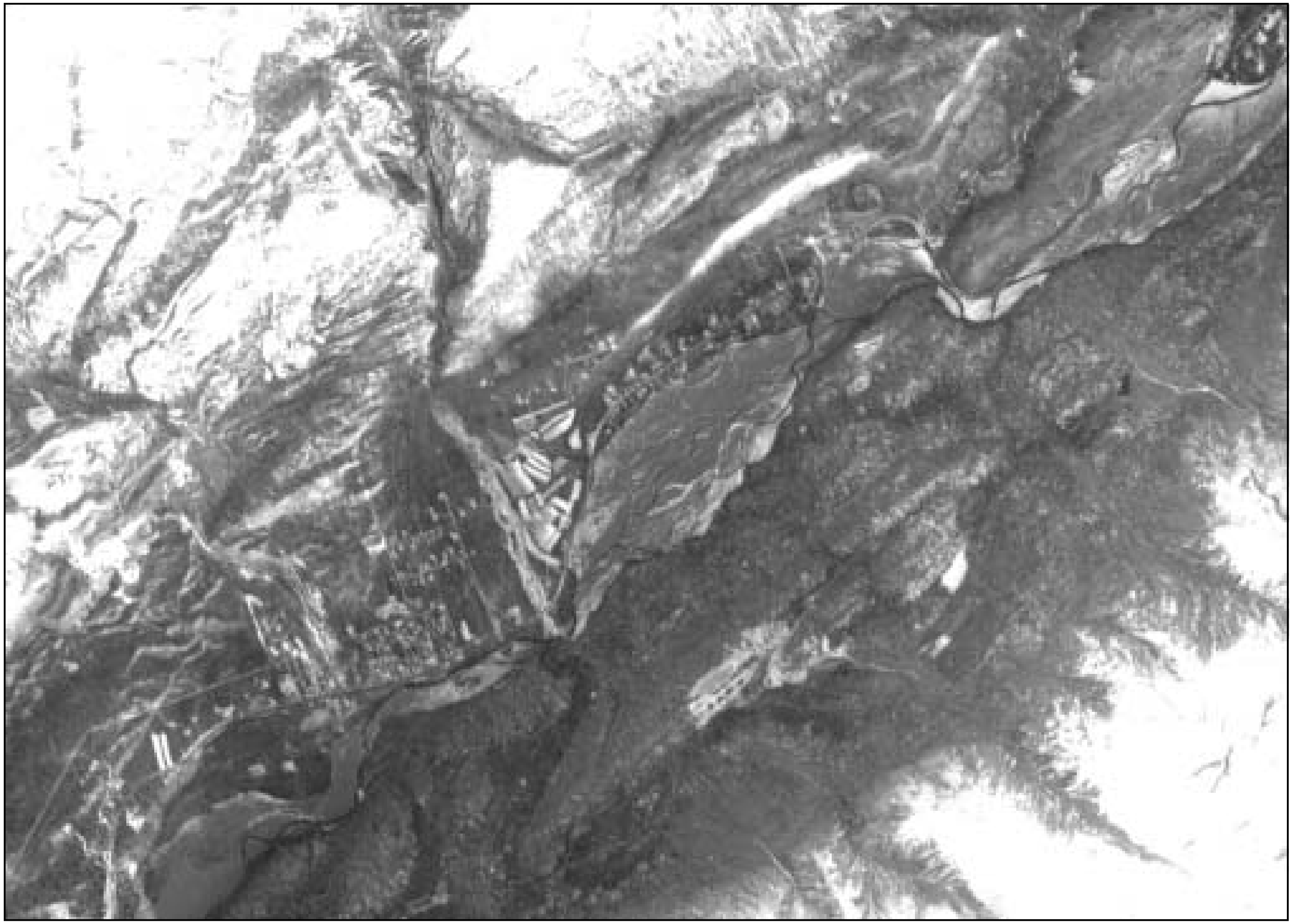
(2000:330, MS 3-2-1)

N

First ALI Image: Sutton, AK

(2000:330, Pan zoom)

N



Washington, DC
(2000:356, MS 4-3-2)

N

Washington, DC

(2000:336, Pan zoom)

N

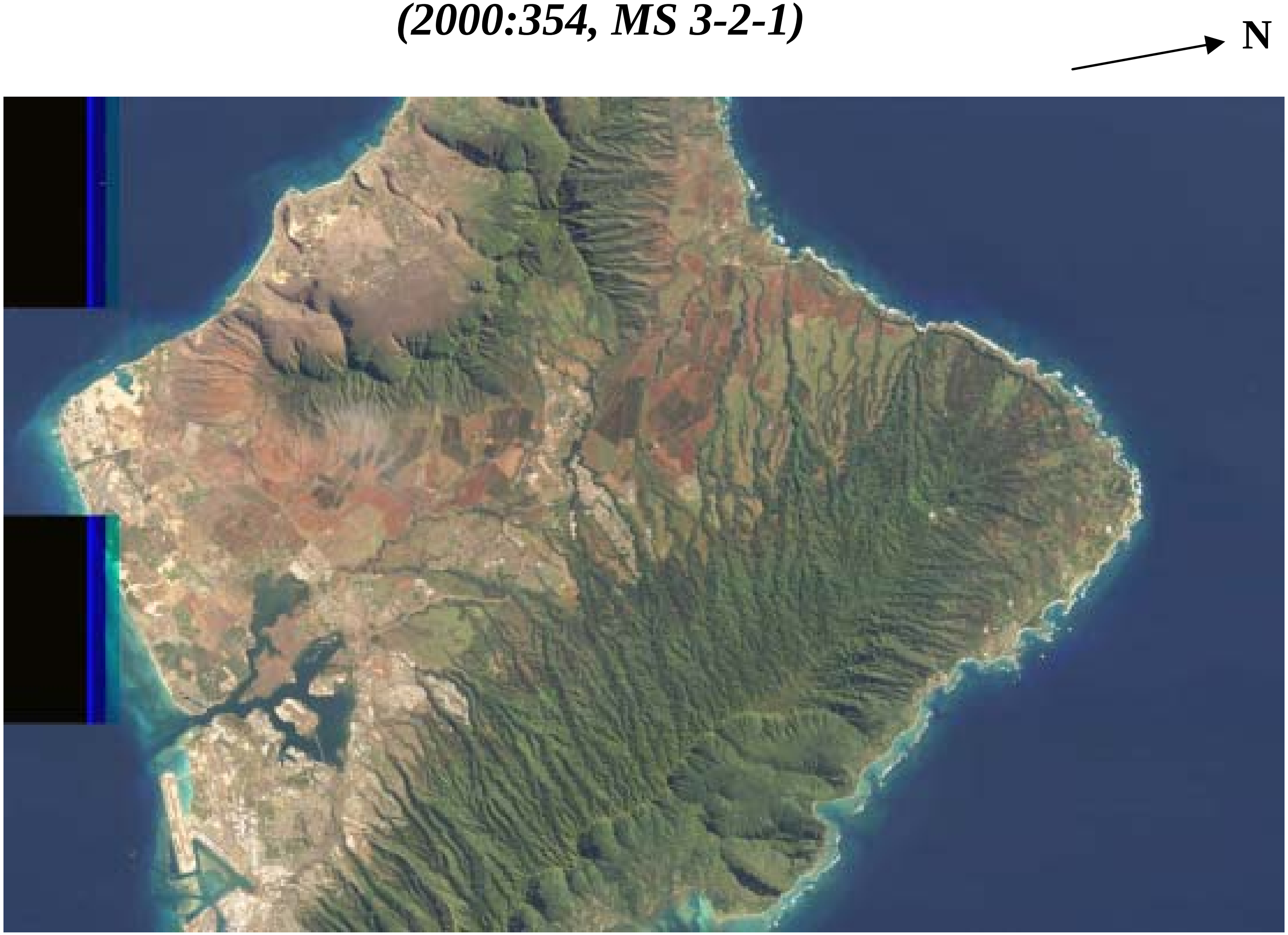
Delaware Coast

(2000:338, MS 4-3-2)

N

Oahu,HI

(2000:354, MS 3-2-1)



Focal Plane Functional Tests

- ***Zero signal noise characteristics***
- ***Internal lamp illumination***
  - ***Responsivity***
  - ***Linearity***
  - ***Stability***
  - ***Contamination assessment***
  - ***On-orbit sensitivity to FPA and optics temperature***
  - ***Evaluation of dead and under performing pixels***
- ***Focal plane decontamination***

ALI Technology Validation: Spatial Tests

- *Functional test of end to end imaging*
- *Focus*
  - *Point spread*
  - *Edge spread*
  - *Line spread*
  - *MTF*
- *Relative pixel line of sight*
- *Band to band image displacement accuracy*
- *Image artifacts*

ALI Technology Validation: Radiometric Tests

- *Pixel to pixel calibration (flat field)*
- *Calibration stability*
- *Absolute calibration*
  - *In-band*
  - *Band to band*
- *Dynamic range*
  - *Saturation*
  - *Noise*
- *Sensitivity (SNR)*
- *Solar calibration*
- *Lunar calibration scan*
- *Calibration corrections for leaky pixels*
  - *Linearity*
  - *Dynamic range*
- *Stray light effects*
  - *Spatial*
  - *Radiometric*

Generic Data Collection Events (DCE)

A. *Large flat metropolitan area with shore line*
   - *High contrast edge lines and points*
   - *Well known locations of key features*

B. *Extended high albedo source with small dark regions*
   - *Clouds over ocean*

C. *Steep topography*

D. *Long bridges*

F. *Large area with uniform known radiance (5-50% albedo)*

G. *Adjacent regions with sharp boundaries and having different, uniform, but not necessarily known radiance levels*

H. *Large area with uniform but unknown radiance*

J. *MODIS calibration sites*

K. *Landsat 7 geometric calibration sites*

L. *Sun*

M. *Moon*

N. *Closed Cover (dark current)*

O. *Night view of brightly lit metropolitan area*

S. *Ground truth and under-flight targets*

T. *Long duration target*

U. *Angular dependence demonstration*

Summary

- *The performance of the Advanced Land Imager in space has been nominal.*
- *The radiometric calibration coefficients will be revised based the imaging of known ground scenes and the solar calibration.*
  - *An improved algorithm has been developed to deal with the two leaky pixels.*
  - *Weekly bake-outs of the focal plane will be conducted to boil off the accumulating contaminants.*
- *The required data base is been collected and will be followed by in-depth analysis of all aspects of instrument performance.*

Section 6

Hyperion Grating Imaging Spectrometer

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

Outline

- ***Driving Requirements***
- ***Design Overview***
- ***Performance Requirements***
- ***Calibration/Characterization***
- ***Flight Validation***

Hyperion Driving Requirements

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

Purpose of Hyperion on EO-1

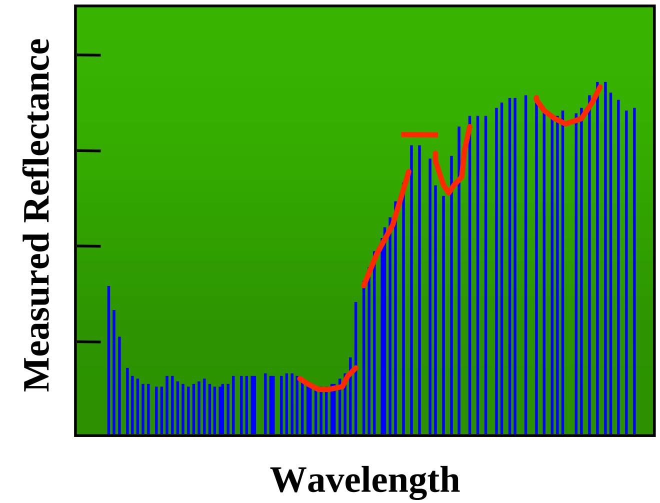
- ***Hyperion is the first hyperspectral imager in space, demonstrating this new technology***
  - *Hyperion will set the standard for hyperspectral imagery, enabling NASA to establish minimum requirements for future data buy*
- ***Hyperion FOV is coaligned with ALI's active area to enable cross-calibration of earth scenes with complete spectrum***
  - *Discrete channels on Landsat and ALI can be checked with Hyperion*
  - *Comparison with Terra MODIS and ASTER also planned*
- ***Hyperion satisfies NASA's desire to replace the Hyper-Spectral Imager (HSI) that was lost with the Lewis mission.***
  - *This new technology can provide unique insight into many scientific and commercial disciplines*

Hyperspectral Imaging Applications & Benefits

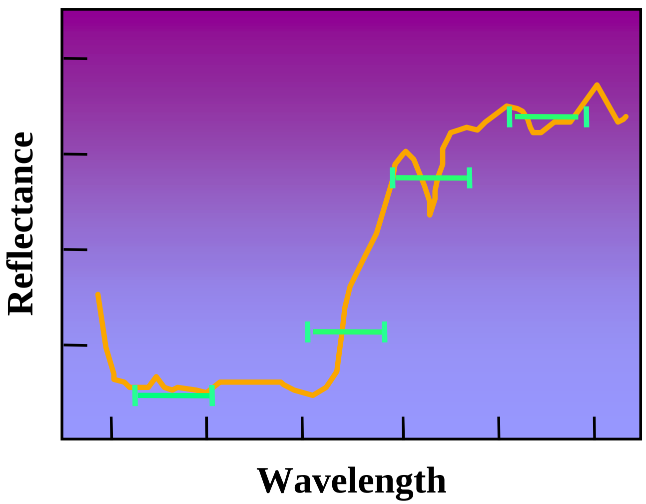
Application	Existing Satellite Capabilities (SPOT, LandSat)	Hyperion Capability	Perceived Benefits
Mining/Geology	Land cover classification	Detailed mineral mapping	Accurate remote mineral exploration
Forestry	Land cover classification	Species ID Detail stand mapping Foliar chemistry Tree stress	Forest health/infestations Forest productivity/yield analysis Forest inventory/harvest planning
Agriculture	Land cover classification Limited crop mapping Soil mapping	Crop differentiation Crop stress	Yield prediction/commodities crop health/vigor
Environmental Management	Resource meeting Land use monitoring	Chemical/mineral mapping & analysis	Contaminant Mapping Vegetation Stress

Hyperspectral and Multispectral Scene Characterization

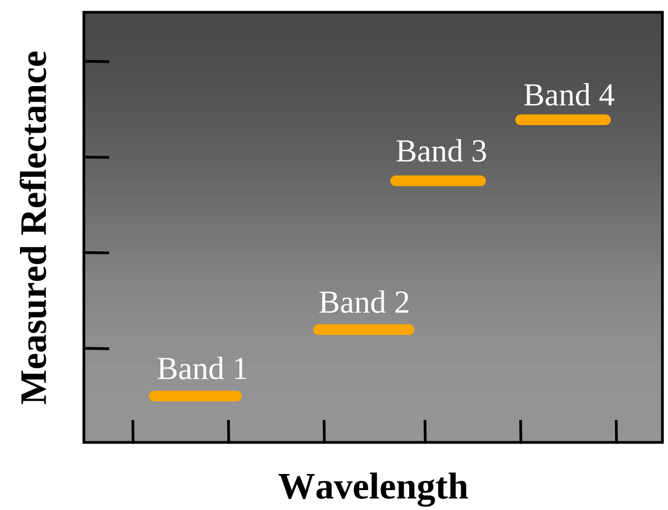
Hyperspectral Imaging
Hundreds of bands



Spectral characteristic of scene



Multispectral Imaging
Few bands



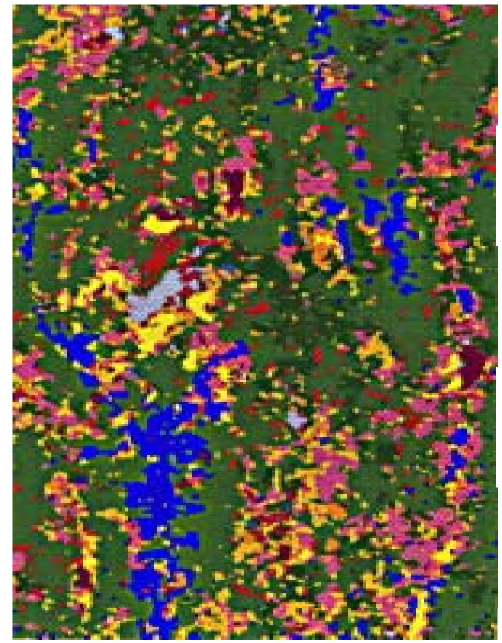
Hyperspectral Image Provides Forestry Detail

LandSat Analysis

Legend

- No Data
- Hardwood
- Softwood
- Grass / Fields

Hyperspectral Analysis



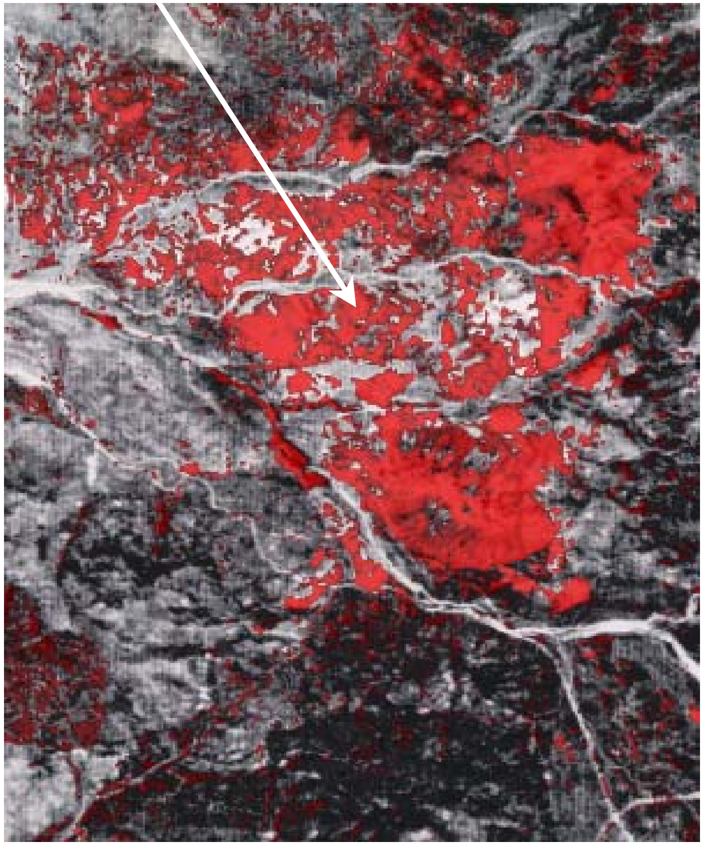
Legend

- No Data Open field
- Hemlock/ Hardwood Mix
- Red Maple
- Mixed Conifer
- Red Oak
- Norway Spruce
- Mixed Hardwood
- Red Pine
- Hardwood/ Conifer Mix
- Spruce Swamp
- White Pine
- Hardwood Bog

Analysis by Mary Martin University of New Hampshire

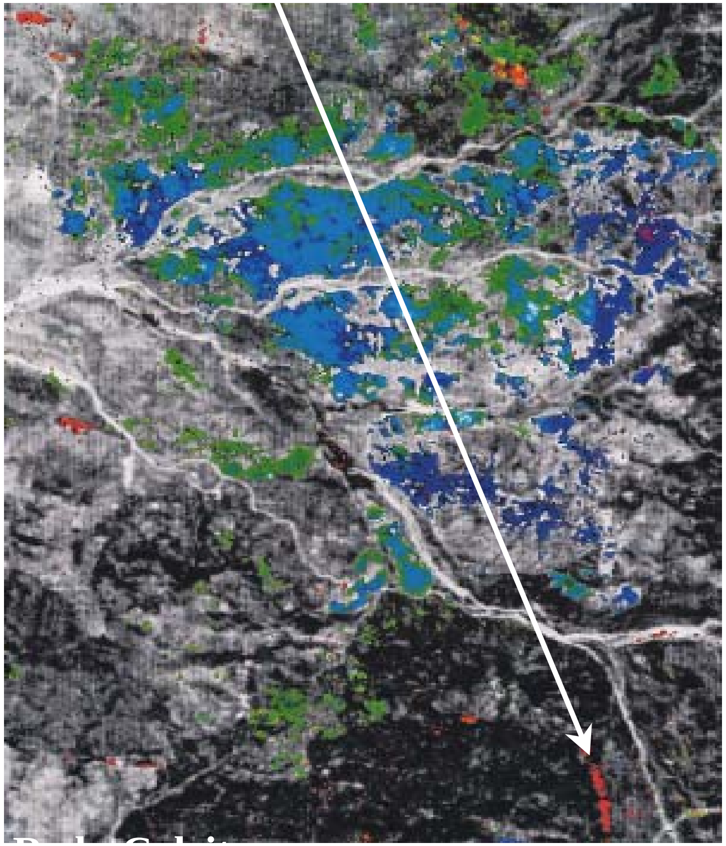
Hyperspectral Image Provides Geological Data

GEOTHERMAL AREA
(no specific mineral information)



MULTISPECTRAL ANALYSIS

CALCITE
(gold bearing quartz)



HYPERSPECTRAL ANALYSIS

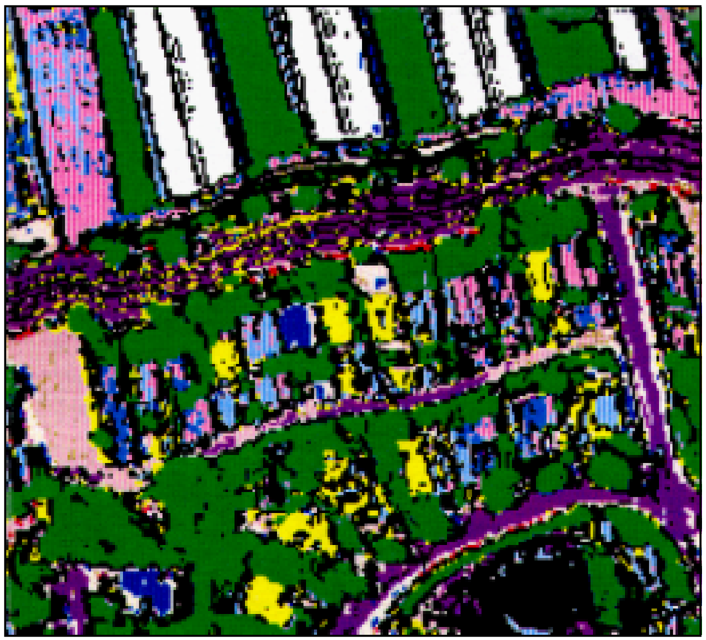
Analysis courtesy AIG Limited Liability Company

Roof Analysis and Mapping Project - Redondo Beach Middle Schools

Objective: Provide detailed map of roof composition clusters for Redondo Beach, CA fire department

Aerial Photo

Roof Composition Analysis Using Hyperspectral Data

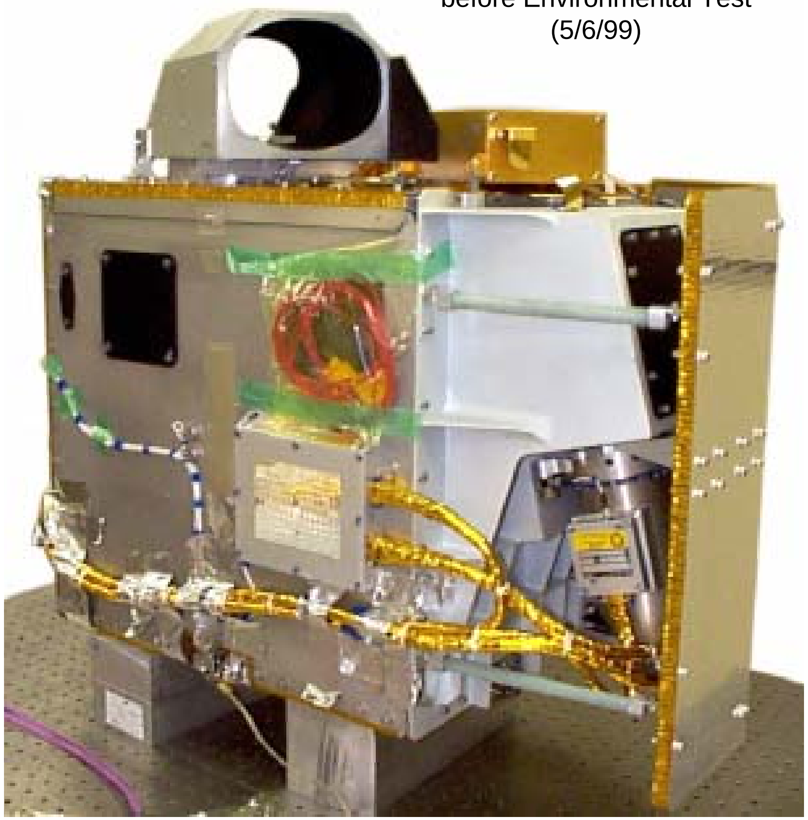


Asphalt 1
Asphalt 2
Asphalt 3
Wood
Tile

Hyperion Hyperspectral Imager

- *Hyperion is a push-broom imager with:*
  - *220 10 nm bands covering the spectrum from 0.4 μm - 2.5 μm*
  - *6% absolute radiometric accuracy*
  - *Image swath width of 7.5 km*
  - *IFOV of 42.5 μrad*
  - *GSD of 30 m at 705 km altitude*
  - *12-bit image data*
  - *MTF 0.34 - 0.48*
  - *Power: 51W orbit avg., 126W peak*
  - *Mass: 49 kg*

Hyperion Sensor Assembly before Environmental Test (5/6/99)



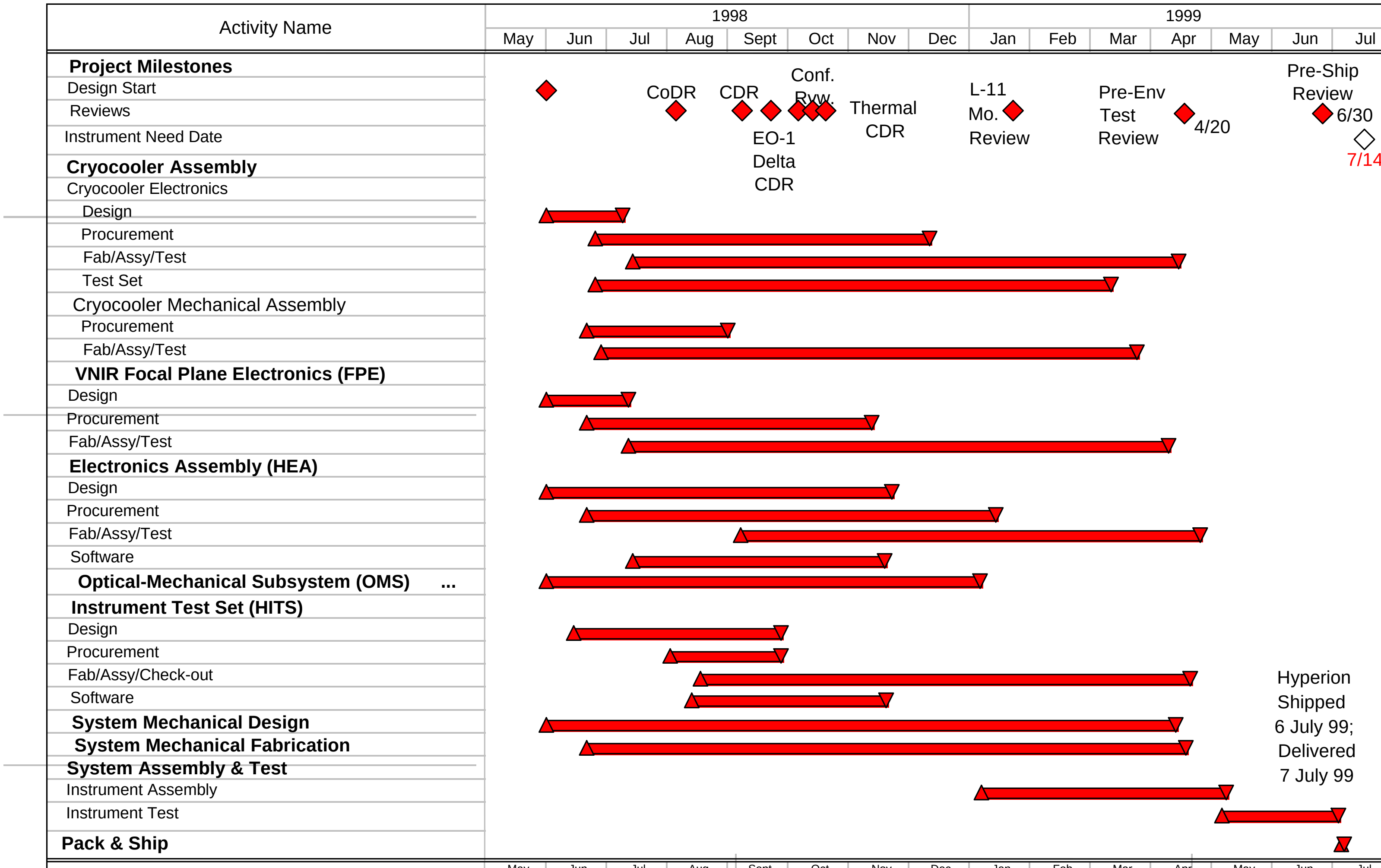
Hyperion
12 months from order to delivery

Hyperion Origins

- ***Following contract termination of planned Grating Imaging Spectrometer (GIS) and Wedge Imaging Spectrometer (WIS) due to technical problems, TRW offered to build Hyperion, a hyperspectral GIS integrated with the Advanced Land Imager (ALI), to be assembled from Lewis Hyperspectral Imager (HSI) spares and delivered to EO-1 in just 12 months***
- ***Hyperion instrument redefined in first week of project as a stand-alone instrument to simplify EO-1 integration by eliminating integration with ALI***
  - ***Added foreoptics and structure design based on spares from the Electro Optical Camera (EOC), another TRW instrument program***
  - ***Schedule remained 12 months to delivery***
- ***Even with a tight one-year schedule, the EO-1 quality requirements and technical design reviews were fully incorporated into the Hyperion program***

Hyperion Master Schedule

Even though Hyperion was an extremely fast-paced program, the parts selection and design standards were not compromised. Hyperion met the GSFC/EO-1 program quality requirements, including numerous reviews.



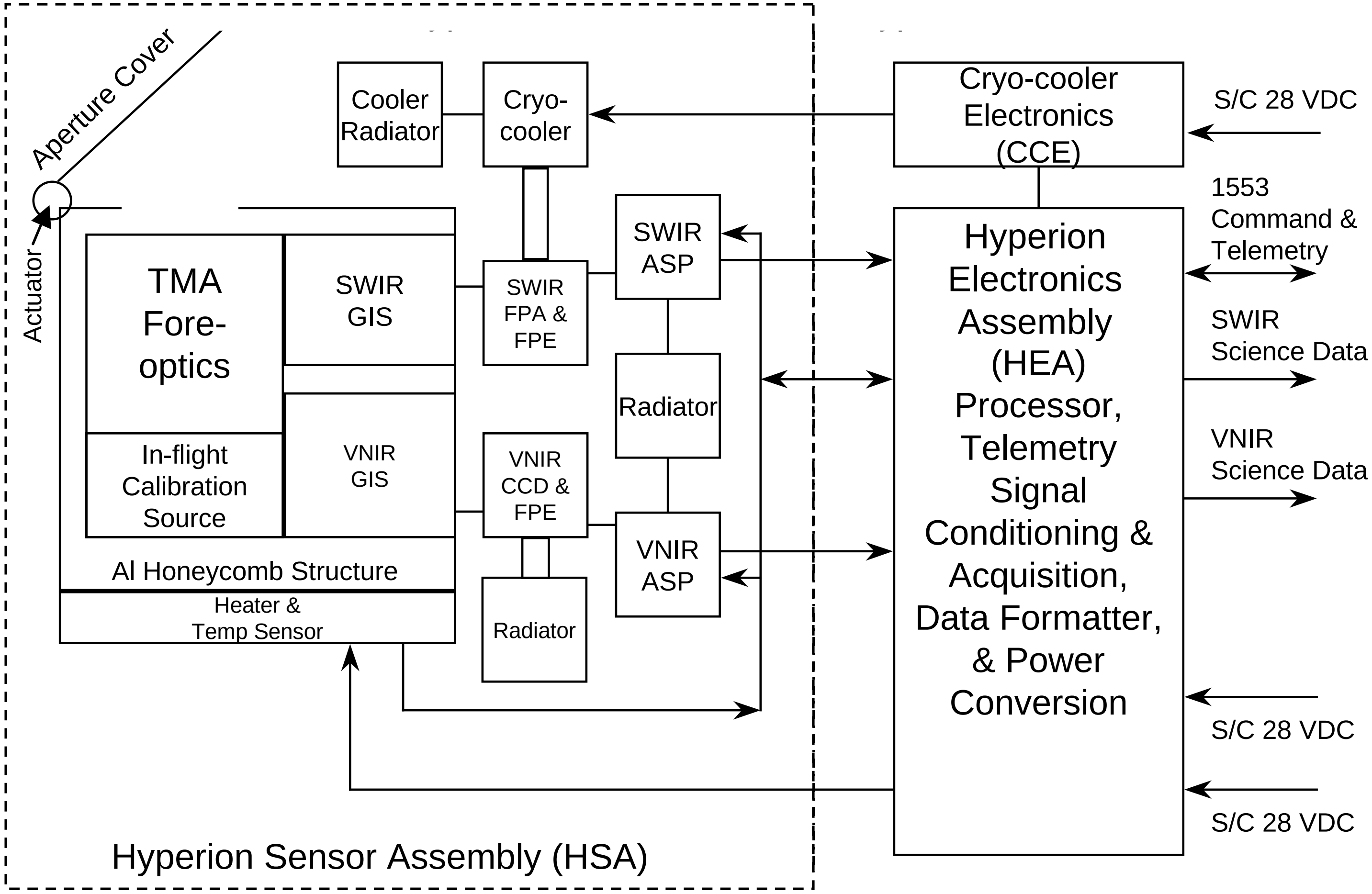
Key System Trades & Critical Analyses

- ***Dichroic Beam Splitter Vs. Dual Blazed Grating***
  - *Selected Dichroic separation of VNIR and SWIR requiring two gratings, improving performance over dual blazed grating*
- ***Instrument Spectral Bandwidth***
  - *Trade to maximize signal-to-noise ratio by optimizing the 10nm spectral width and the number of channels*
- ***Thermal Control of Opto-Mechanical Structure***
  - *Moved heaters from outside of honeycomb enclosure to the OMS structure inside honeycomb enclosure to save heater power.*
- ***1553 / 1773 Conversion***
  - *Selected transceiverless 1553 chip that matched input to EO-1 1773 fiber optic device, avoiding significant expense of developing a separate converter*

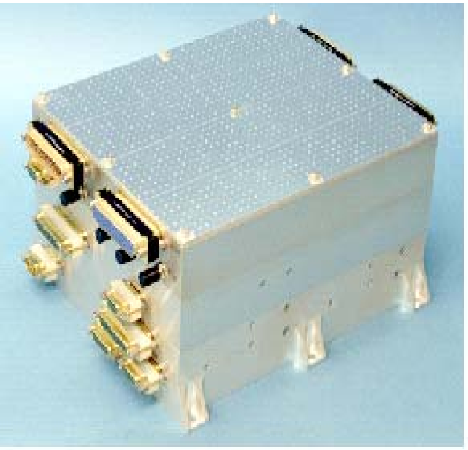
Hyperion Design Overview

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

Hyperion Functional Block Diagram

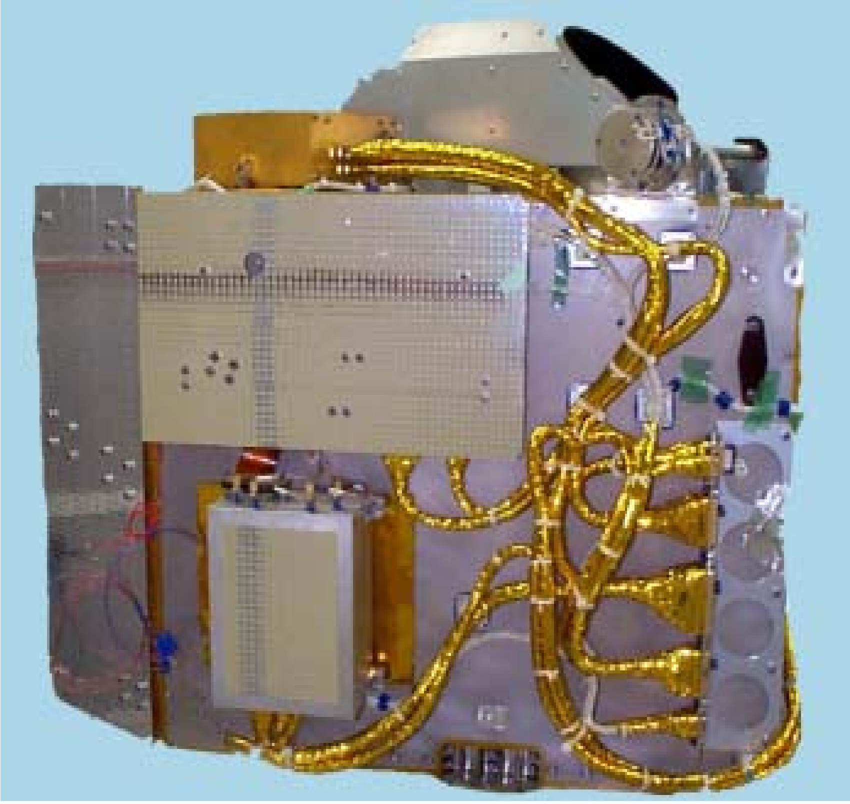


Hyperion Subassemblies



Hyperion Electronics Assembly (HEA)

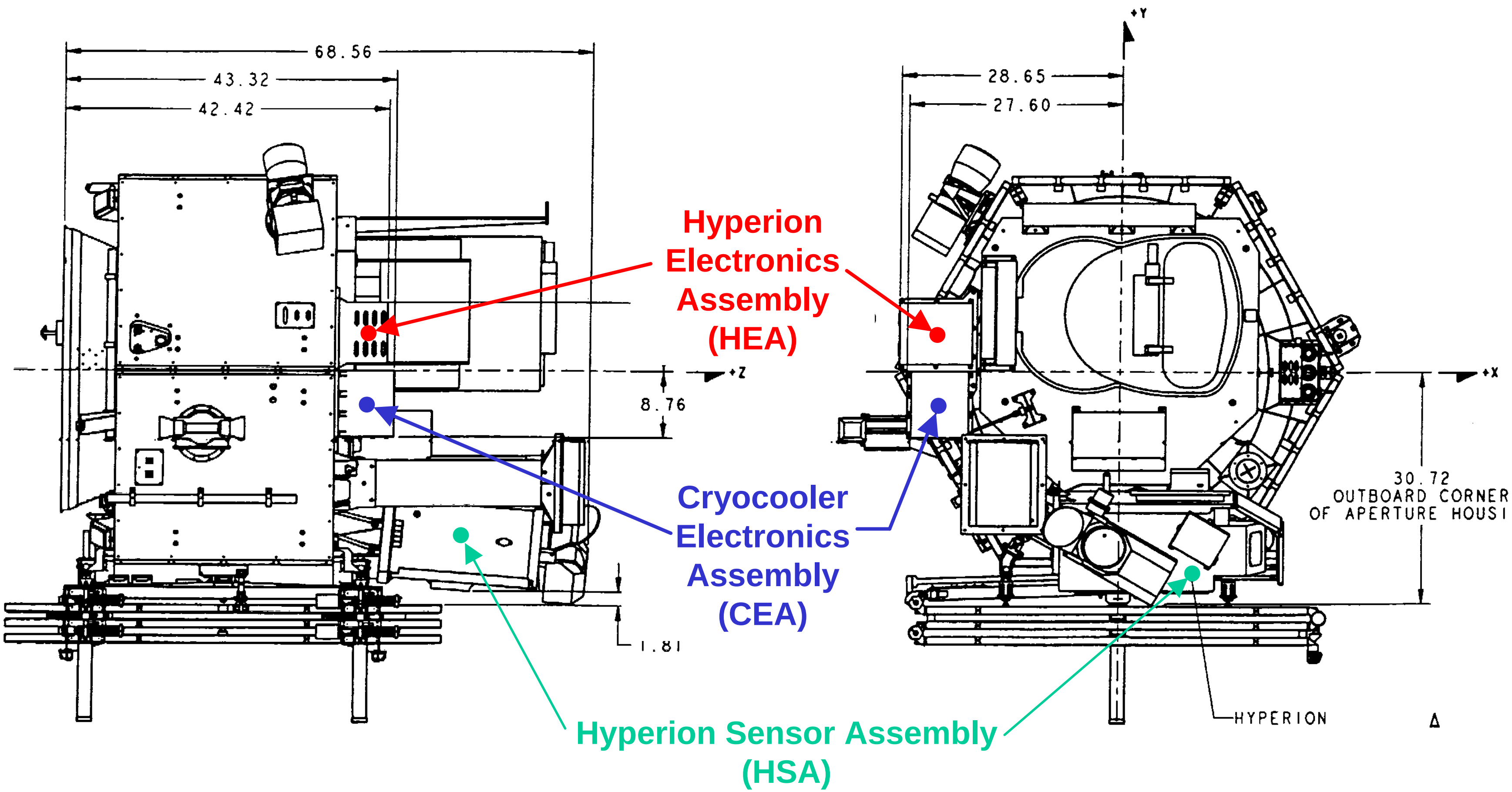
Cryocooler Electronics Assembly (CEA)



Hyperion Sensor Assembly (HSA)

Hyperion Spacecraft Accommodation

HSA, HEA and CEA locations on the EO-1 nadir deck



Hyperion Performance Requirements

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

Hyperion Requirements Flowdown

- Hyperion Mission Requirement EQ7-0459
  - Hyperion NMP EO-1MAR D27445
    - Project Quality Req'ts QPR24662
    - Project Approved Part List D27443
  - Interface Control Document IF1-0228
    - Hyperion S/C Layout A0743
    - S/C Hyperion ICD Drawing A0765
  - Requirement Flow Down Hyper-300-98-001
    - Hyperion Specification EQ7-0459
      - HSA CI No. CHA0100 Dwg TBD
      - Opto-Mechanical Subsystem Spec EQ7-0457
        - •Grating Spec EQ7-0458
        - •Dichroic Spec EQ7-0460
        - •VNIR O-Filter EQ7-0371
        - •SWIR O-Filter EQ7-0369
        - •VNIR FPA Spec EQ2-0272
        - •SWIR FPA Subsystem L513.DI.94-259 Rev. D
      - HEA CI No. CHA0200 Dwg 868590
      - Cryocooler
        - CEA CI No. CHA0300 Dwg. 868650
        - Pulse Tube Ass'y CI No.CHA0400 Dwg. TBD
      - Test Plan Calibration Plan
        - •Functional Test Procedure
        - •Performance Test Procedure
        - •Calibration Procedure
        - •Vibration Test Procedure
        - •TV Test Procedure
        - •EMC Test Procedure
        - •End Item Data Package
  - Operations
    - Validation Plan
    - Operation Manual

Hyperion Performance Requirements

Instrument Parameter	Requirement
GSD at 705 km Altitude	30 +/- 1 m
Swath Width (km)	7.5 km minimum
Spectral Coverage	0.4 - 2.5 μm
Imaging Aperture	12.5 +/- 0.1 cm diameter
On-orbit Life	1 year (2 years goal)
Instantaneous Field of View	42.5 +/- 3.0 μrad
Number of Spectral Channels	220 minimum
SWIR Spectral Bandwidth	10 +/- 0.1 nm
VNIR Spectral Bandwidth	10 +/- 0.1 nm
Cross-track Spectral Error	<1.5 nm (VNIR), <2.5 nm (SWIR)
Spatial Co-registration	<20% of Pixel
Absolute Radiometric Accuracy	<6% (1 sigma)
Data Quantization	12-bit
Operability (SWIR, VNIR)	> 98% each*

Signal to Noise Ratio (SNR)

λ-range (μm)	SNR (min)
0.55-0.70	60
1.0-1.05	60
1.20-1.25	60
1.55-1.60	60
2.10-2.15	30

Modulation Transfer Function (MTF)

	VNIR MTF @ 8.33 l/mm			SWIR MTF @ 8.33 l/mm			
Wavelength (μm)	0.45	0.63	0.90	1.05	1.25	1.65	2.20
Minimum MTF Requirement	0.20	0.20	0.15	0.14	0.14	0.15	0.15

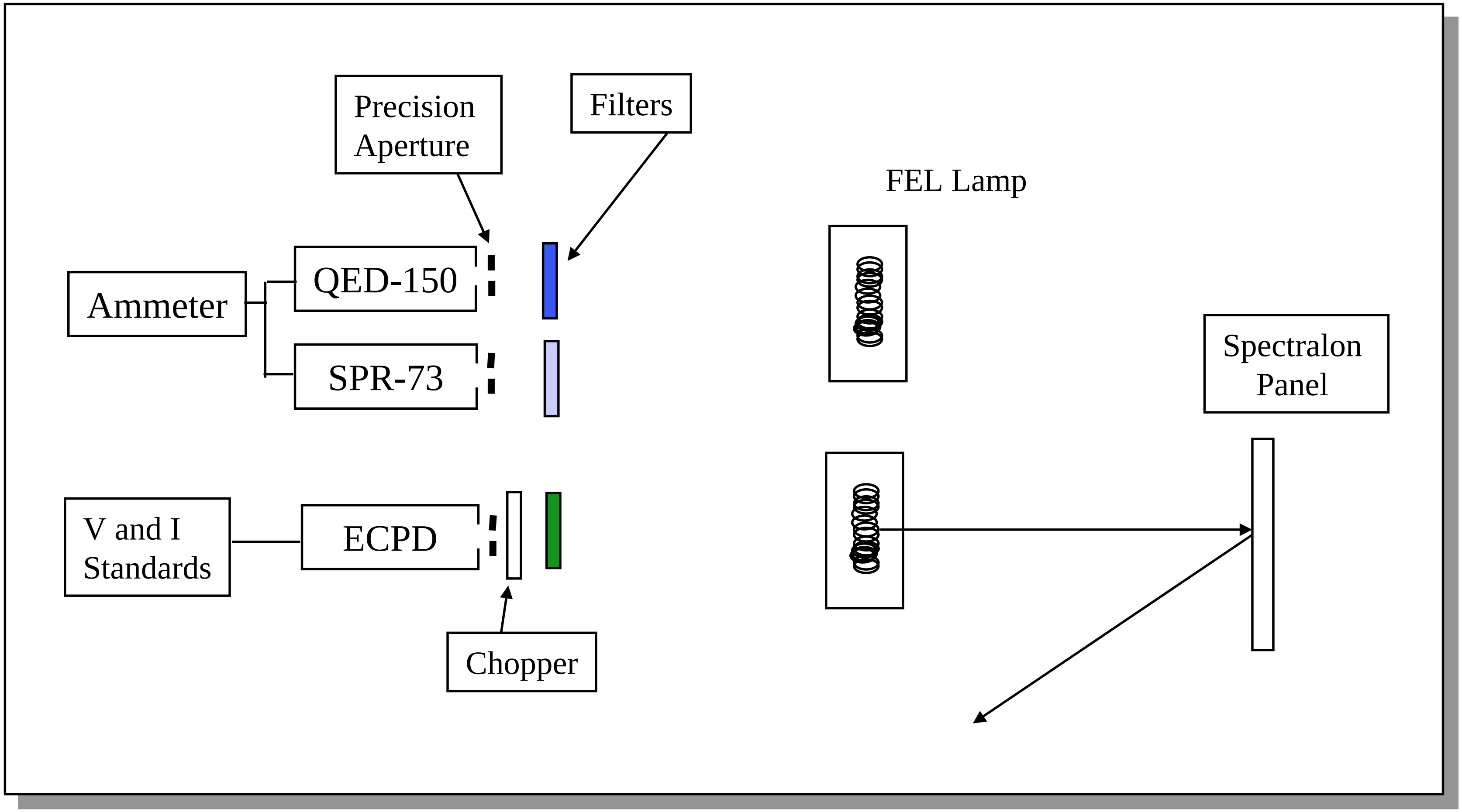
Hyperion Calibration/Characterization

. . . Peter Jarecke
Hyperion Calibration
TRW Space & Electronics

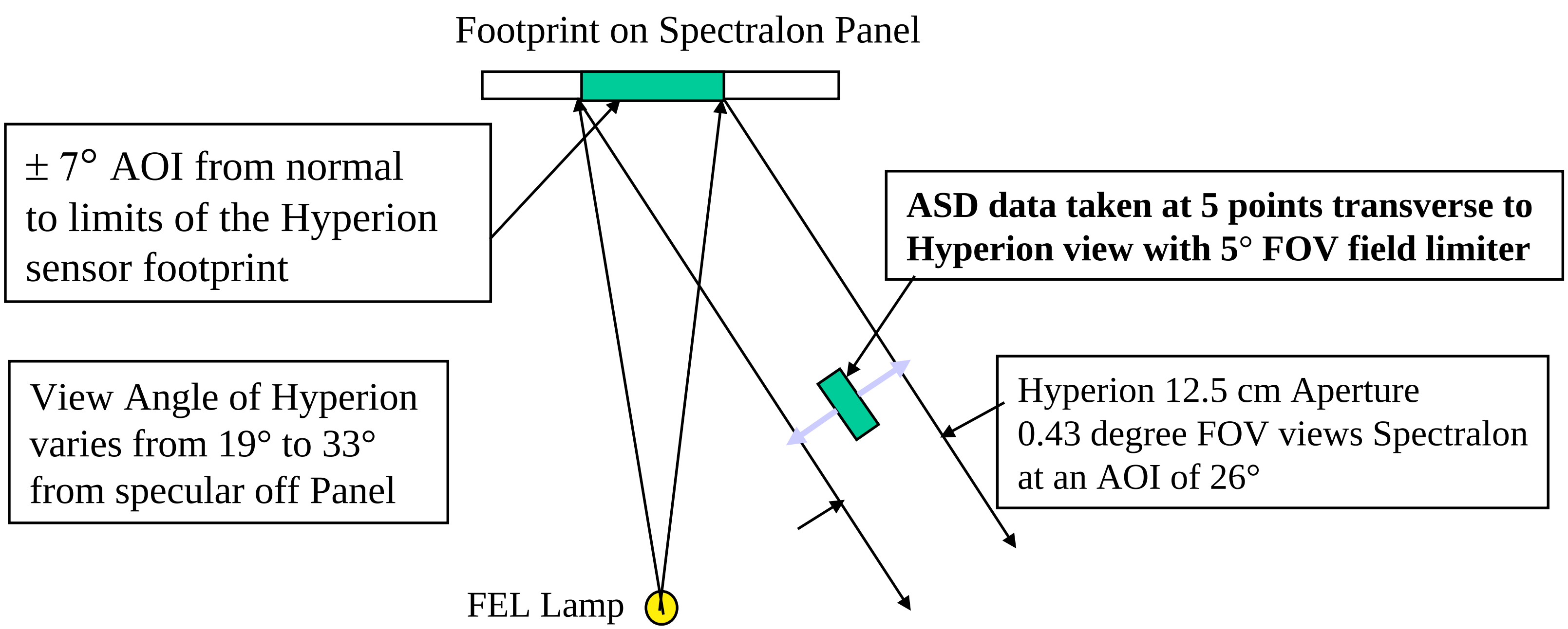
Radiometric Quantities To Be Characterized

- ***FPA Rectilinearity***
  - *Cross-Track Spectral Alignment (CTSA)*
  - *Spatial Co-Registration of Spectral Channels (SCSC)*
- ***Image Quality***
  - *Cross-track and Along-track MTF*
- ***Radiometric Responsivity - Calibration***
  - *Long Term Repeatablity*
- ***Pixel Center Wavelength Calibration***
- ***Signal to Noise***
- ***Ground Sample Distance and Swath Width***

Overview of Calibration Process



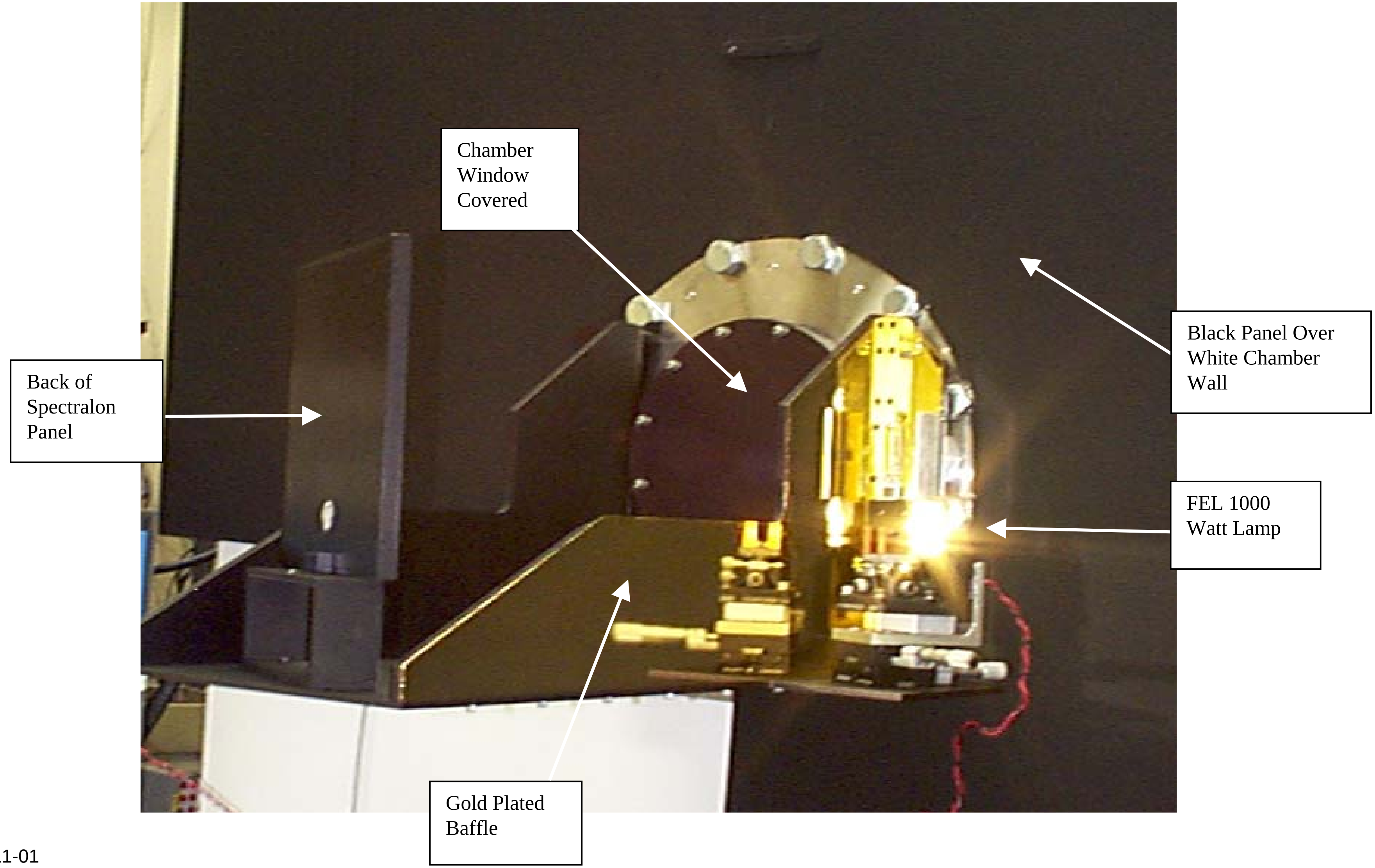
Conversion to Radiance



FEL Incident Irradiance falls as cos³ of the AOI which is a 2.5 % falloff in Irradiance

The BRDF characteristics of the Panel are critical in converting FEL Irradiance incident on the Panel to Radiance. The assumption that the BRDF is flat from 19° to 33° based on vendor data was tested using an ASD Field Spec as shown. ASD data matched the 2.5 % falloff to ± 0.3 %

Spectralon Panel Assembly Installed



Hyperion Radiometric Characterization Facility

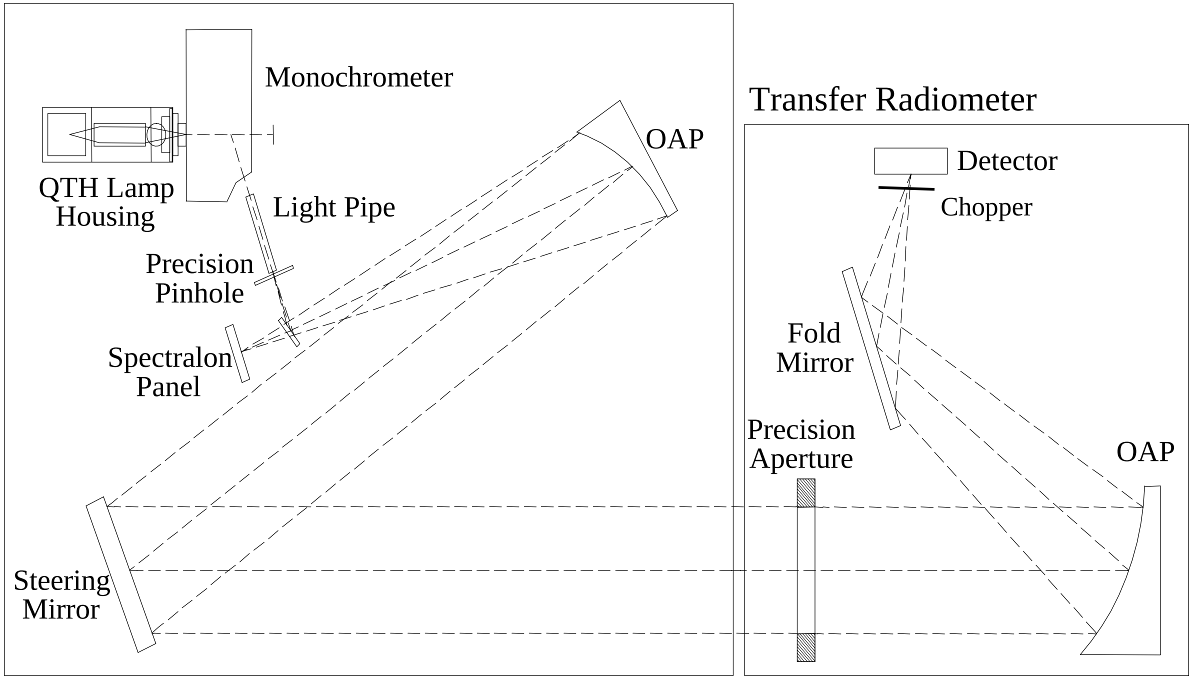
Formerly Known as the MSTB - Upgraded for Hyperion Characterization

Two modes of Operation:

1) Pinhole, slit and/or Knife Edge at end of light pipe put at focus of OAP
2) End of light pipe is re-imaged onto Spectralon panel.

Both are shown simultaneously in chart without re-imaging optics

Steering mirror is a two axis, fine pointing mirror (± 1–2 μrad) for sub-pixel scanning in spatial dimensions

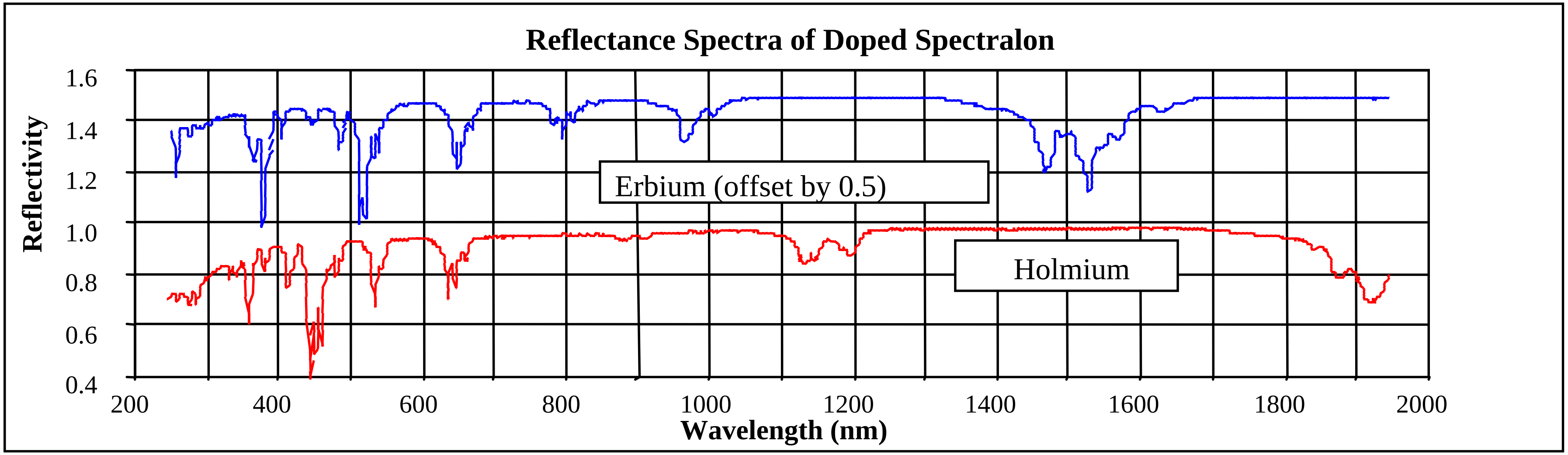


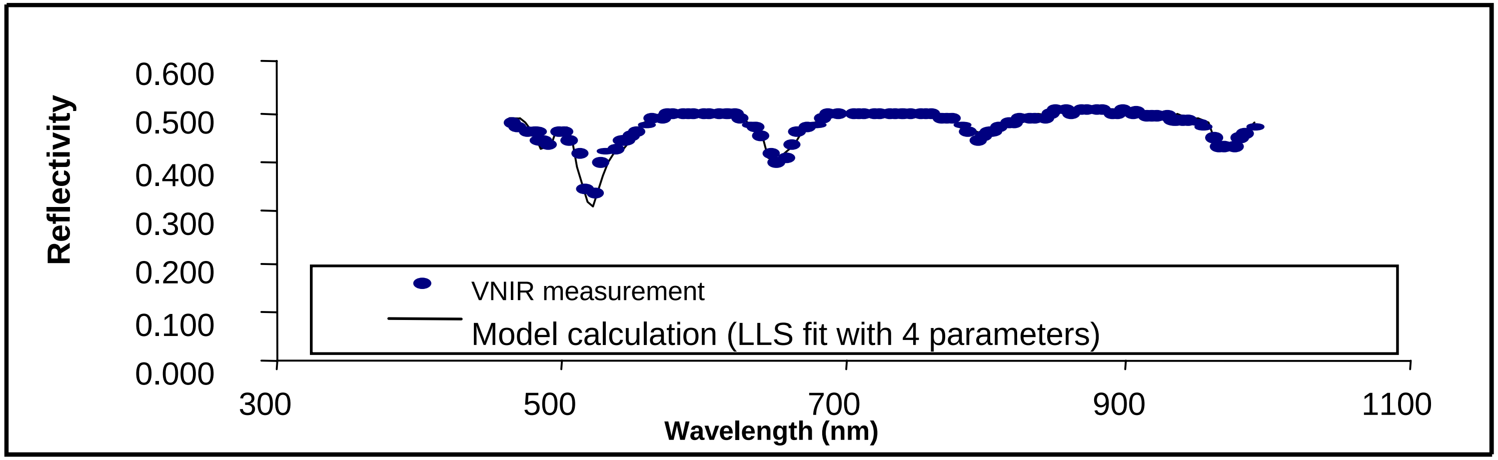
The transfer radiometer is a removable box for calibration of the Characterization Facility output.
It uses a chopped pyroelectric detector traceable to the TRW primary irradiance scale.
An accurate AΩ is calculated from precision apertures and OAP focal length.

Spectral Wavelength Calibration

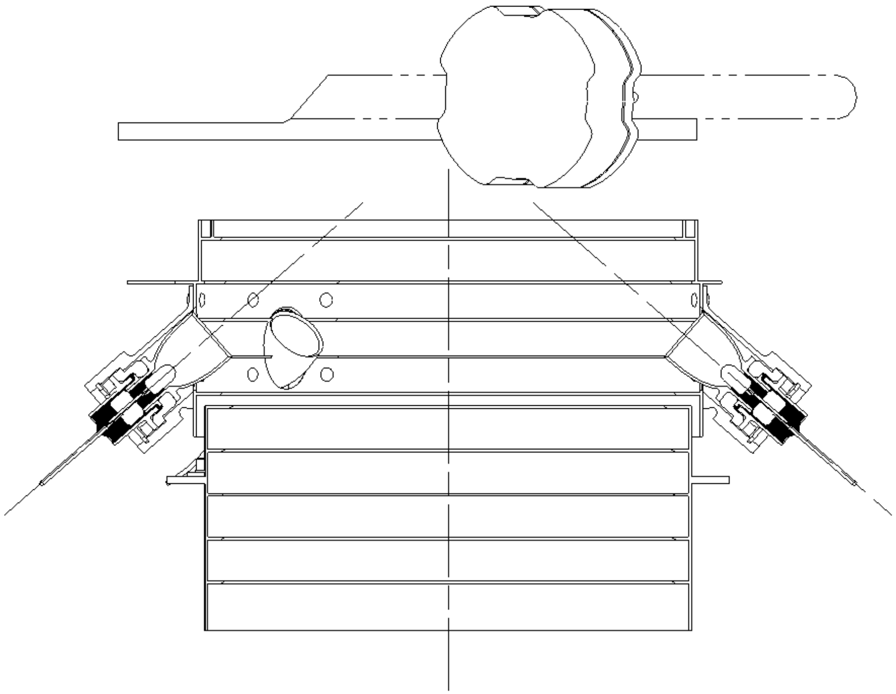
- *High resolution scans of the Holmium and Erbium Oxide doped Spectralon are shown in the next chart.*
- *Two sensor data frames are taken: one from a doped Spectralon panel and one from a high reflectance Spectralon panel.*
- *The ratio of these two frames removes lamp illumination source wavelength variations and sensor response variations.*
- *To derive a calculated curve for the above data, the high resolution scans are convolved with the sensor spectral response function. This degrades the high resolution scans to the lower sensor resolution.*
- *A linear least squares (LLS) regression of the data points with the curve fixes the wavelength calibration of the sensor. Each spatial FOV position is calibrated in wavelength simultaneously for all spectral pixels saving time greatly.*
- *The linear regression at each FOV position allows three constants for wavelength values at the pixel center (i.e. a second order fit in l versus pixel number). The width of the sensor pixel response function is also allowed to take on a best fit value for the LLS.*
- *The accuracy of the fit is about 0.02 pixels (judgement call based on the width of the standard error minimum of the LLS fit)*

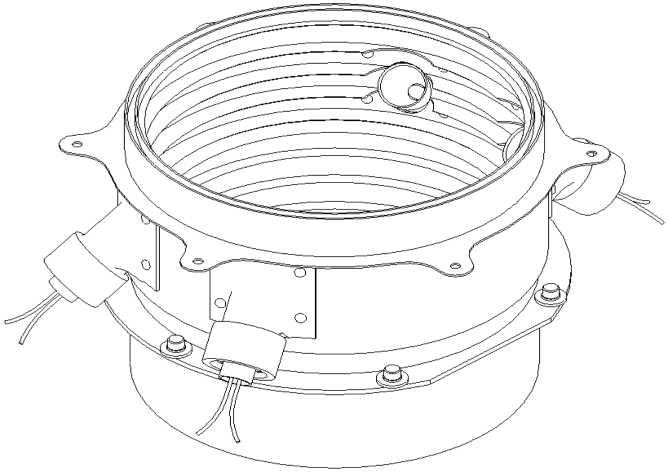
Spectral Wavelength Calibration

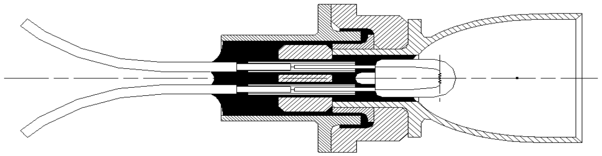




In-Flight Radiometric Calibration







On-Orbit Calibration Verification

Item	Req.	Ground	On-Orbit Approach
Absolute	< 6%	<6%	will combine solar calibration, lunar calibration, internal calibration and vicarious calibrations to address absolute calibration (refer to flow chart) models of sun and moon are required error budgets associated with vicarious calibration required
Linearity		linear (~1%)	will assume linear and verify (if possible) using results of the absolute calibration events
Calibration Source Stability			calibration lamp image obtained with each DCE and performance of the lamp will be trended absolute measure of lamp radiance will be performed when making absolute measurements described above results compared with calibration values and suspected drift

Radiometric Long Term Monitoring Plan

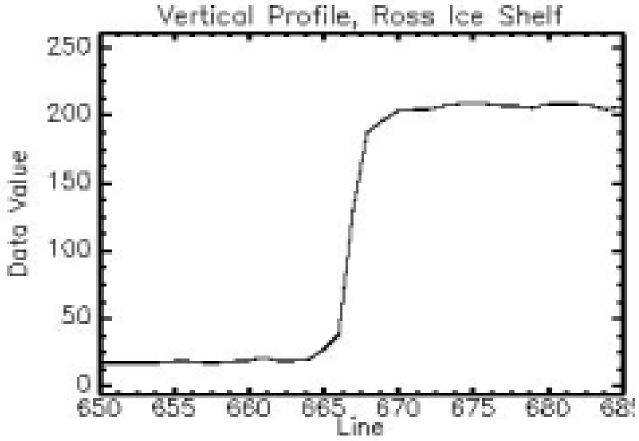
Item	On-Orbit Approach
Stability	scenes identified as being repeatable will be obtained multiple times and compared: Saharan, TBR sites selected for vicarious calibration can also be used especially if obtained multiple times response from calibration lamps will be trended
Temperature Sensitivity	VNIR: ASP temperature controlled, FPE temperature sensitivity will be established SWIR: ASP temperature could be controlled, FPE temperature is controlled by the cryocooler orbital temperature variations will be trended
Flatfield (streaks)	use internal calibration lamp to adjust for time of scene gain changes if present

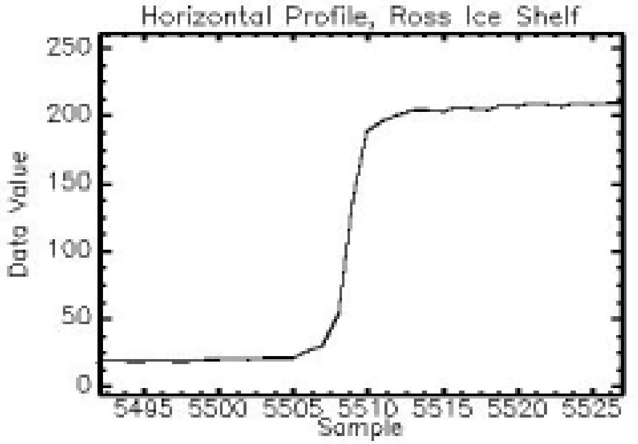
Image Quality

Item	Req.	Ground	On-Orbit Approach
GSD	30 m ±1m	29.88 m	Use scenes that contain objects with known separation distance, need ground truth of scene potentially use digital images: Cities ex: El Segundo, Active Illumination determine pixel distance between centroid of independent features need multiple measurements to de-couple cross track and along track distance
Swath Width	> 7.5 km	> 7.5 km (7.65 km)	Extension of cross track GSD and number of used FOV pixels
Swath Length		160 km based on 24 second DCE	Extension of along track GSD and length of DCE

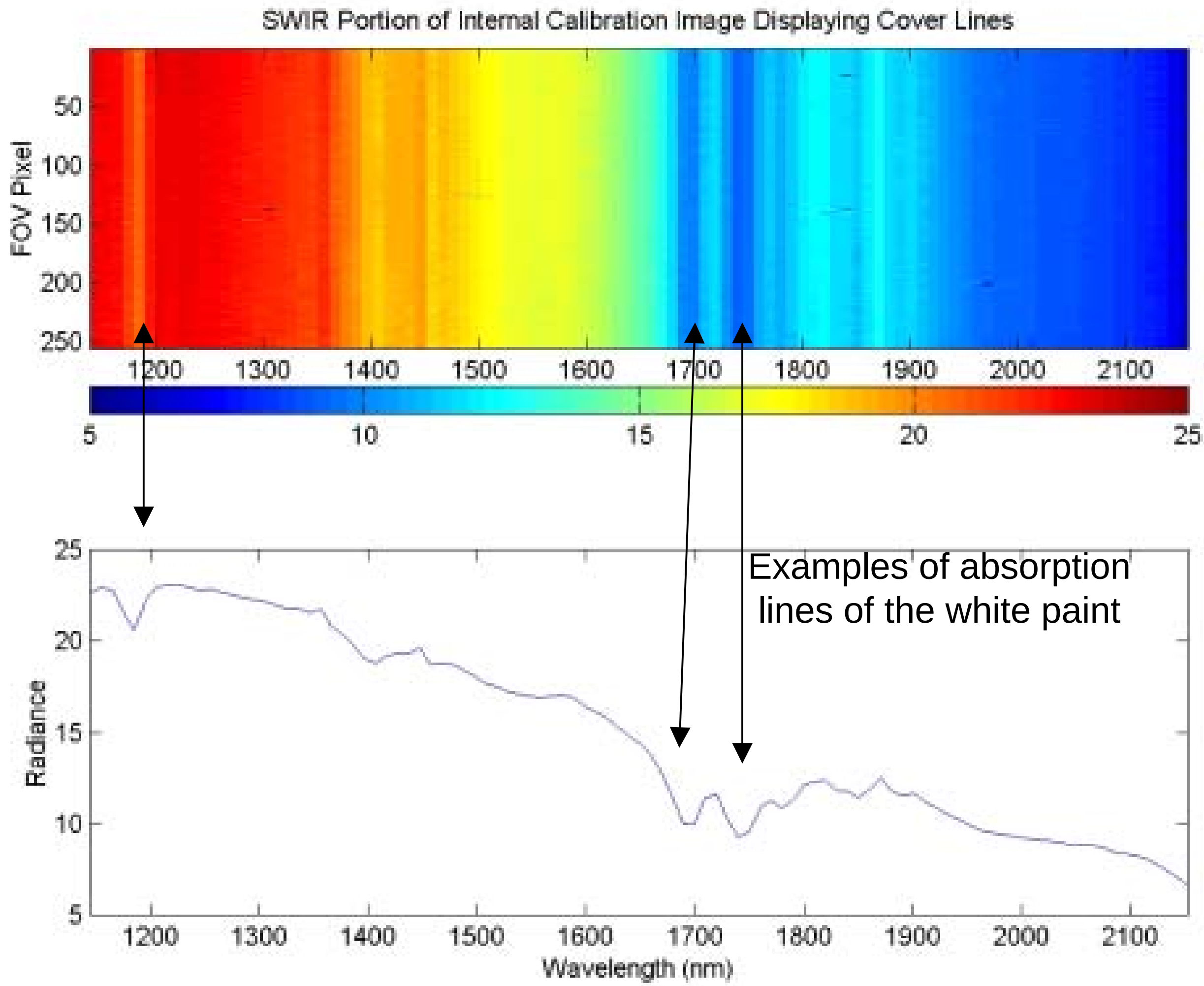
Image Quality Example

Vertical and Horizontal MTF can be calculated from diagonal edge





Spectral Calibration Using Internal Calibration System



Hyperion Flight Validation

. . . Dr. Carol Segal
Hyperion Deputy Project Manager, Mission Operations
TRW Space & Electronics

Hyperion Performance Verification

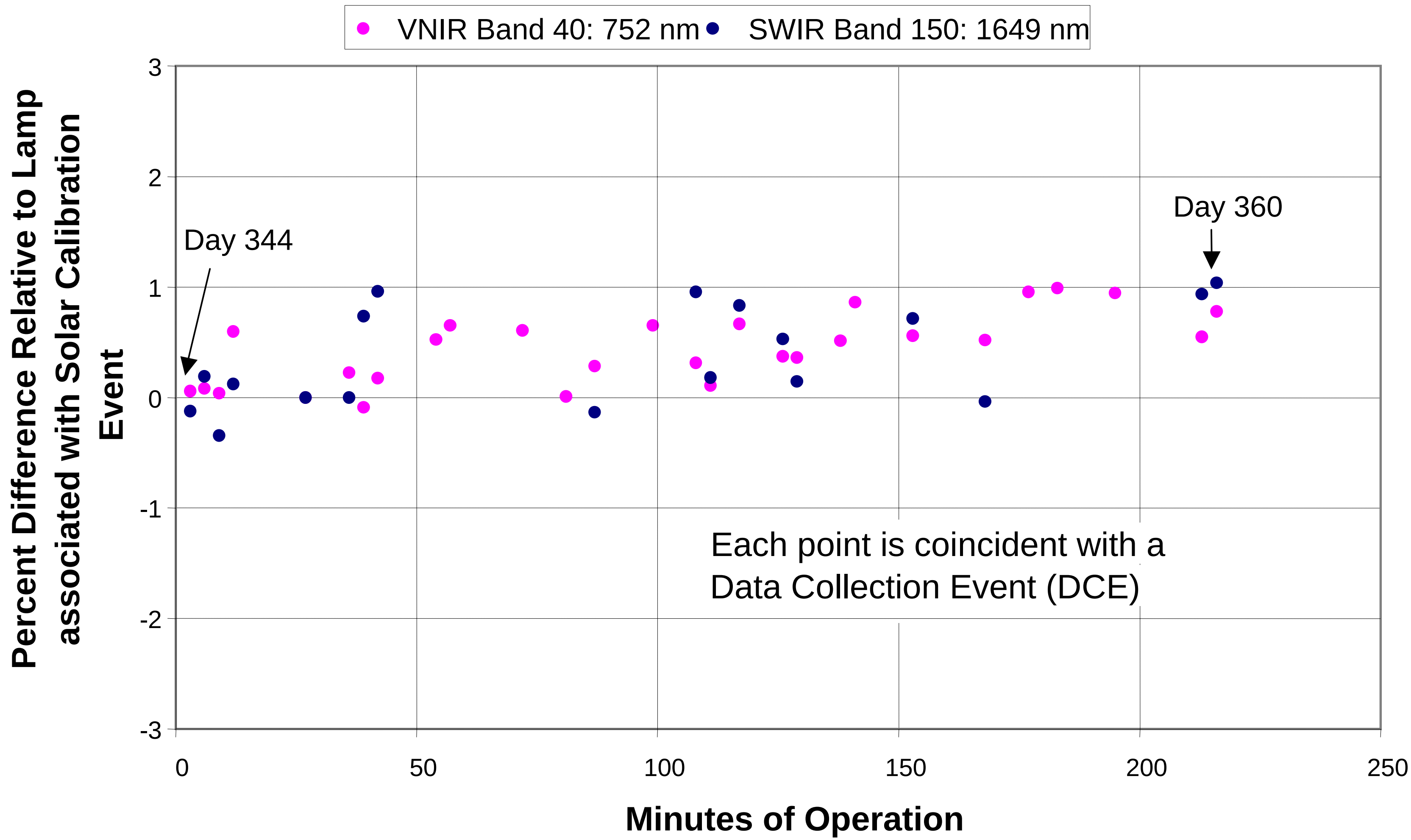
- ***The On-orbit Performance Verification Plan was completed in preparation for the on-orbit 60 day checkout period:***

Phase	Description	Day	Function
1	Initial VNIR Turn On	6	Perform Instrument Functional Tests
2	Heated Outgassing	7-17	Monitor Trended Parameters VNIR Internal Calibration Assess Processing Turn-around time VNIR Earth Image Collection
3	Instrument Verification Assess Readiness for Characterization	18-30	Cryocooler Operational – SWIR Turn-on SWIR Internal Calibration VNIR SWIR Earth Image Collection
4	Instrument Characterzation Calibration	18-60	Assess Instrument Performance Initialize Long Term Characterization

Hyperion Activation

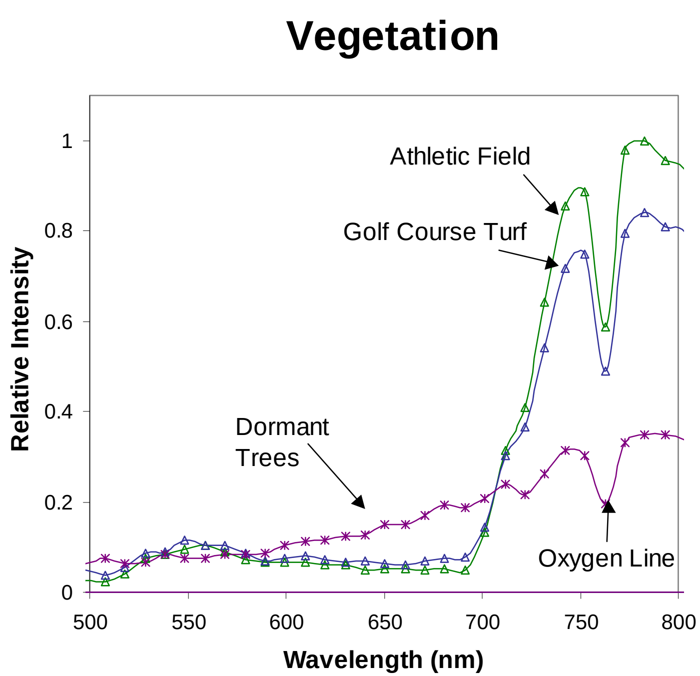
Instrument Subsystem	Activation Date/Time	Current Status
HEA	27 Nov 00, GMT=332:1232	(phe-)NOMINAL
Analog Signal Processors	27 Nov 00, GMT=332:1410	(phe-)NOMINAL
Heaters	27 Nov 00, GMT=332:1600 – all heaters cycling @ nominal temps	(phe-)NOMINAL
Internal Calibration Lamps	27 Nov 00, GMT=332:1427	(phe-)NOMINAL
Aperture Cover	27 Nov 00, GMT=332:1915	(phe-)NOMINAL
VNIR Focal Plane (1st image)	27 Nov 00, GMT=332:1601 – internal cal 28 Nov 00, GMT=333:0526 -- ground	(phe-)NOMINAL
Cryocooler	29 Nov 00, GMT=334:1716 – functional test 8 Dec 00, GMT=343:1426 – 1st cooldown	(phe-)NOMINAL
SWIR Focal Plane (1st SWIR image)	8 Dec 00, GMT=343:1921 – internal cal 8 Dec 00, GMT=344:0030 -- ground	(phe-)NOMINAL

On-Orbit Repeatability of Calibration Lamp

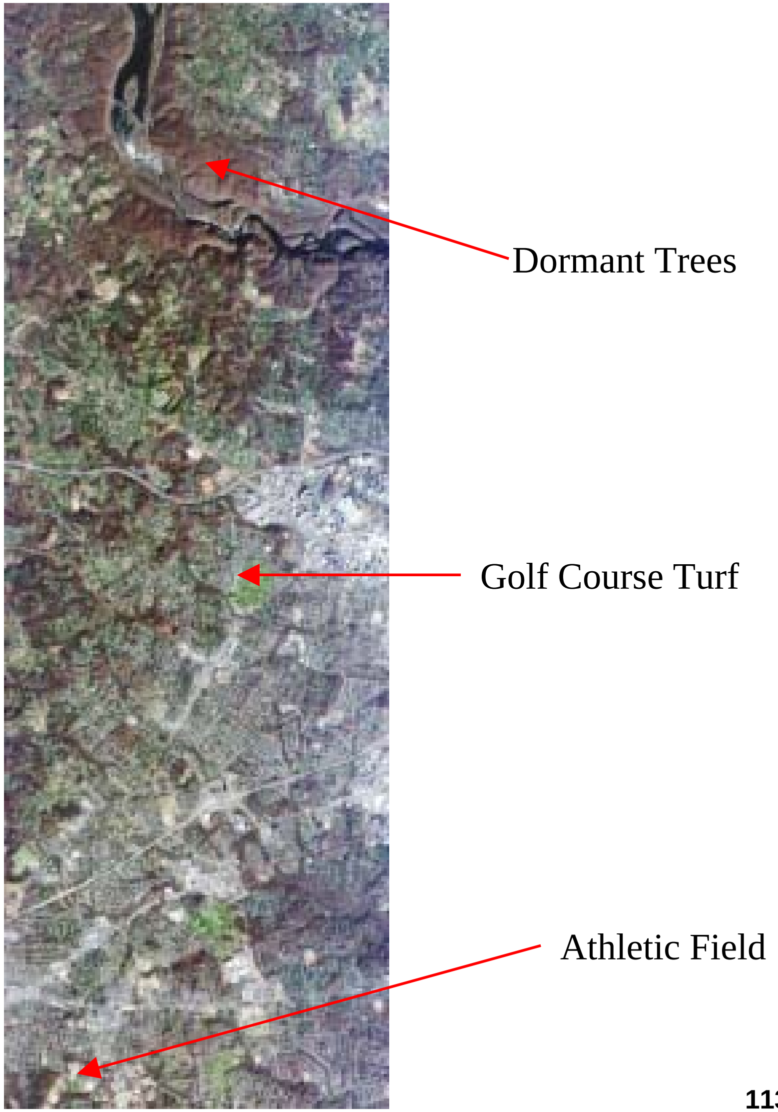


Hyperion Image of Fairfax, VA December 2000

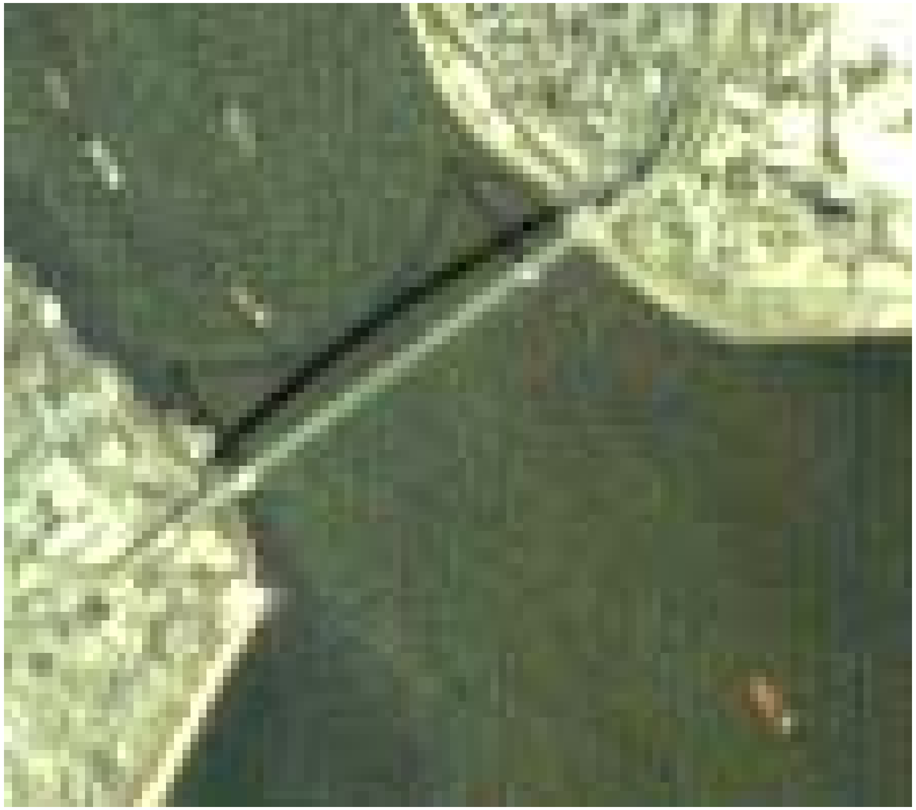
Image taken by Hyperion shows the relative chlorophyll content of vegetation in Fairfax County. The spectral profiles indicate healthy grass in the athletic field and golf course. The spectral profile of the trees indicates dormant vegetation.



Oxygen in the atmosphere is detected by the spectral profiles in the near infrared wavelength.

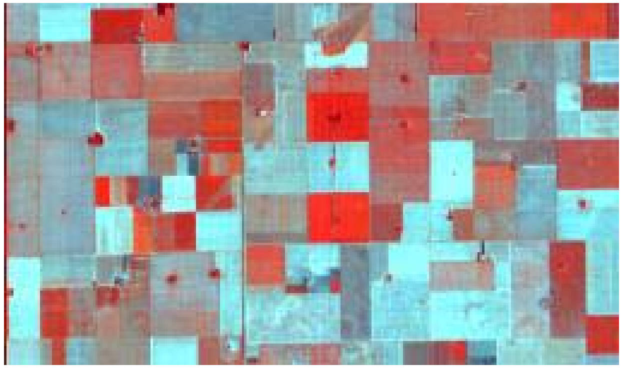


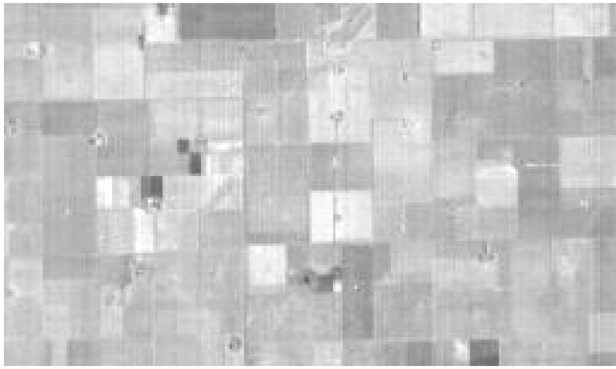
Verrazano-Narrows Bridge, New York



Geometric: Example

VNIR Band 30: ~650 nm





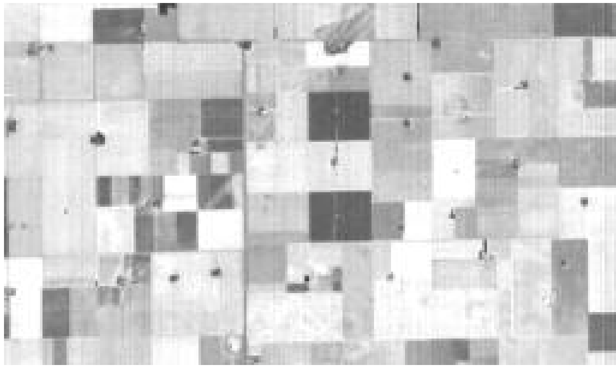
SWIR Band 85: ~993nm

Cordoba Soybean

False RGB, Red is healthy vegetation: 51,23,16

~(864,578,507 nm)

VNIR Band 40: ~752 nm



SWIR Band 150: ~1649 nm

Oahu, HI

Tariquia, Bolivia

Visible RGB

False RGB Representing Pixel Purity

Section 7

LEISA Atmospheric Corrector (LAC)

. . . Dennis Reuter

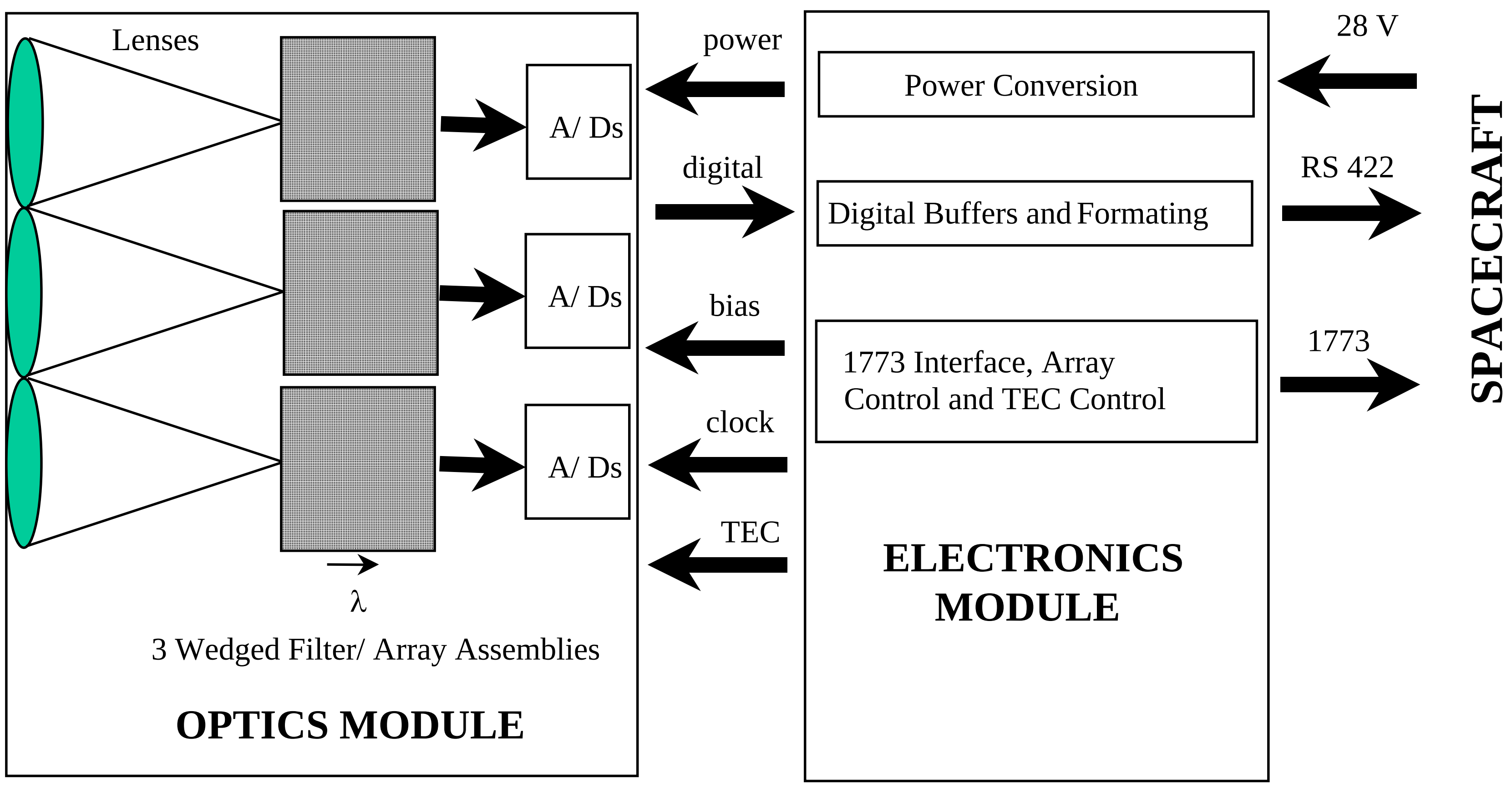
Requirements

- ***Correct High Spatial Resolution Multispectral Imager Data for Atmospheric Effects***
- ***Hyperspectral Imager***
- ***Moderate Spectral Resolution (<10 nm)***
- ***Moderate Spatial Resolution (<300 meter)***
- ***Minimize Impact on Spacecraft Resources***
- ***Maximize Flexibility***

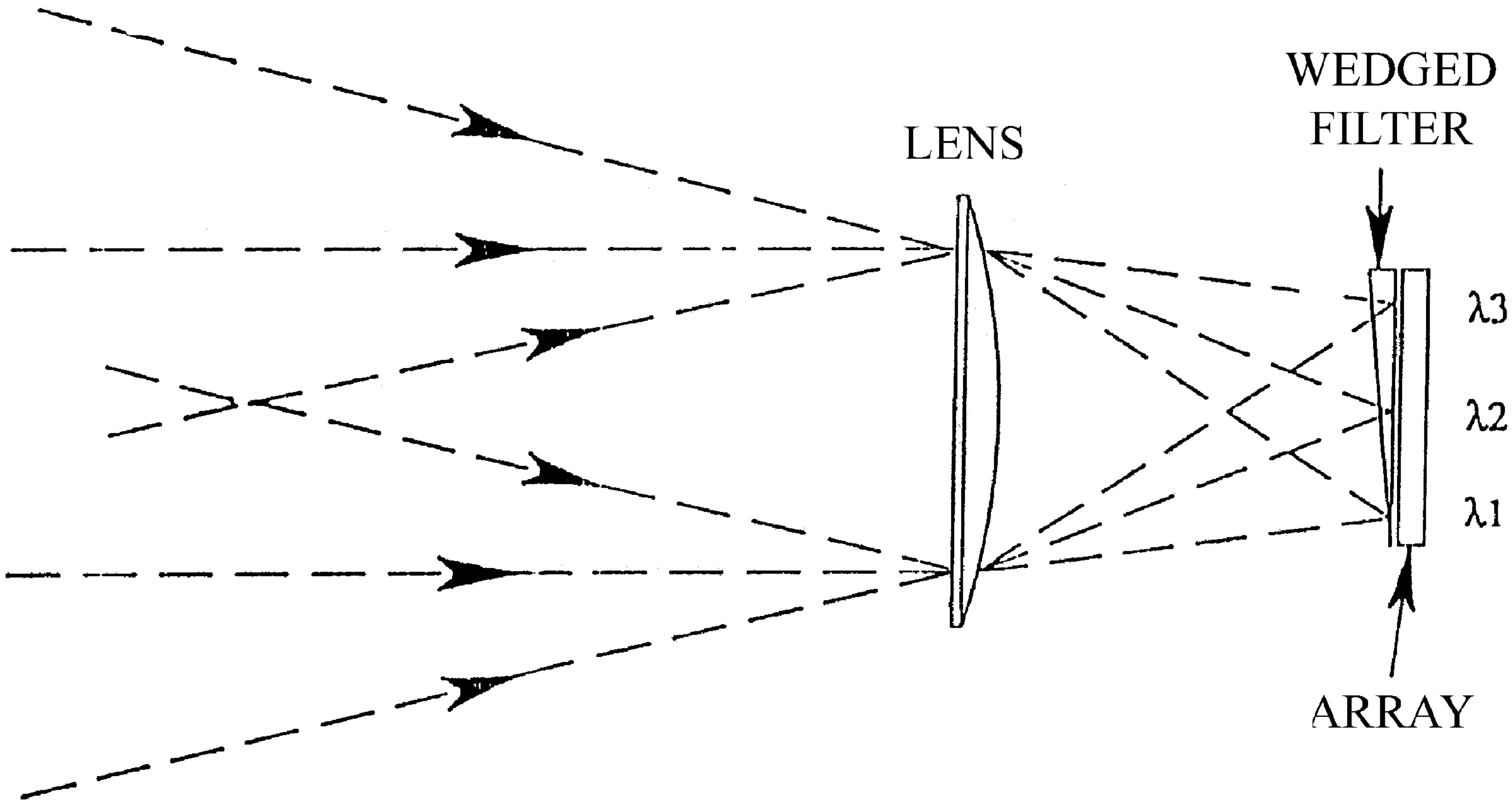
Contribution to EO-1

- ***Validation of Wedged Filter Approach for Spacecraft Instrumentation***
- ***Atmospheric Correction for ALI Multispectral Images.***
- ***Atmospheric Correction for Landsat-7 Images (Formation Flying).***
- ***Direct Study of Spatial Resolution Degradation (Cross-Comparison with Hyperion).***
- ***Retrieved Atmospheric Parameters.***
- ***Cross-Comparisons with MODIS.***

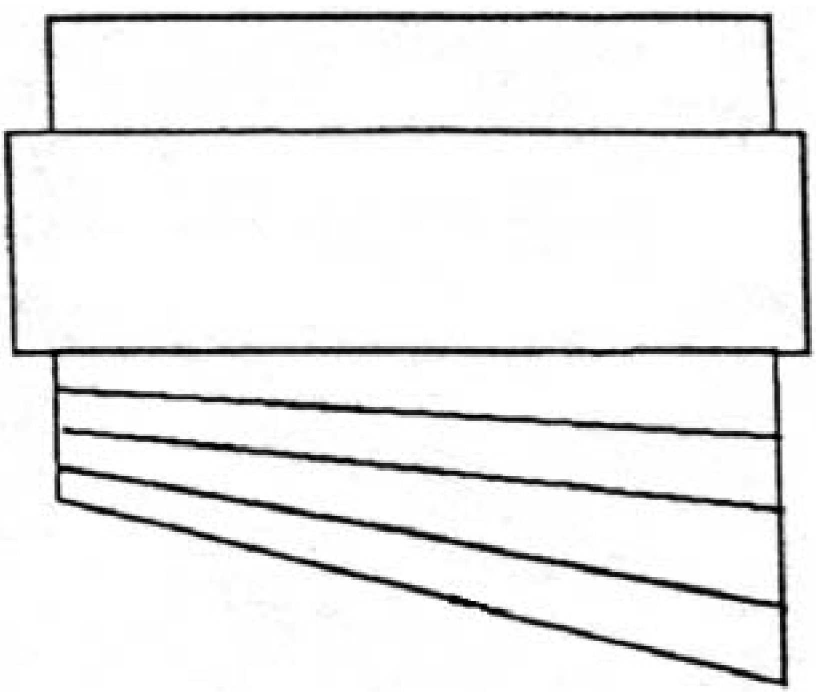
LAC Block Diagram



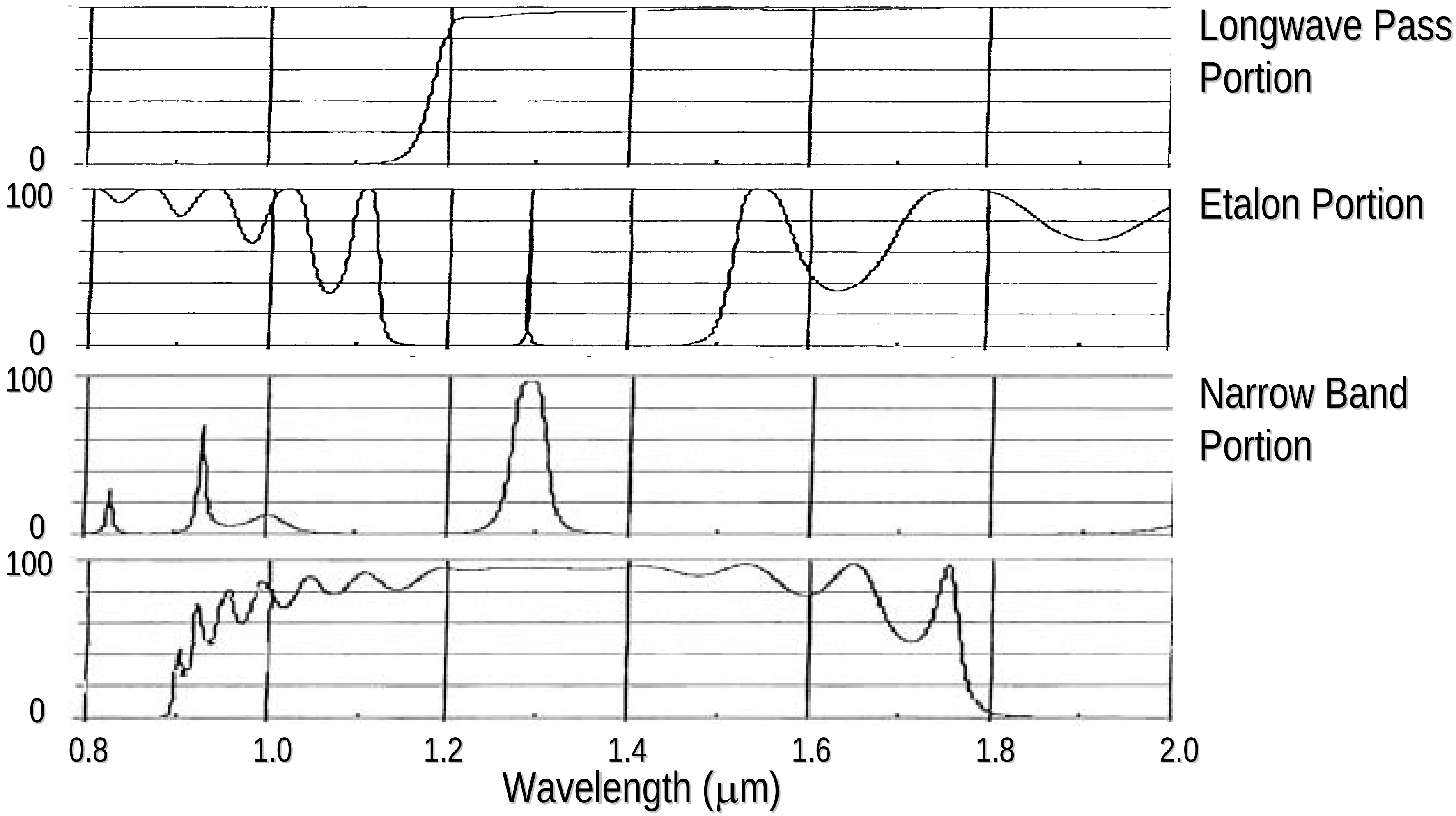
Wedged Filter Operation



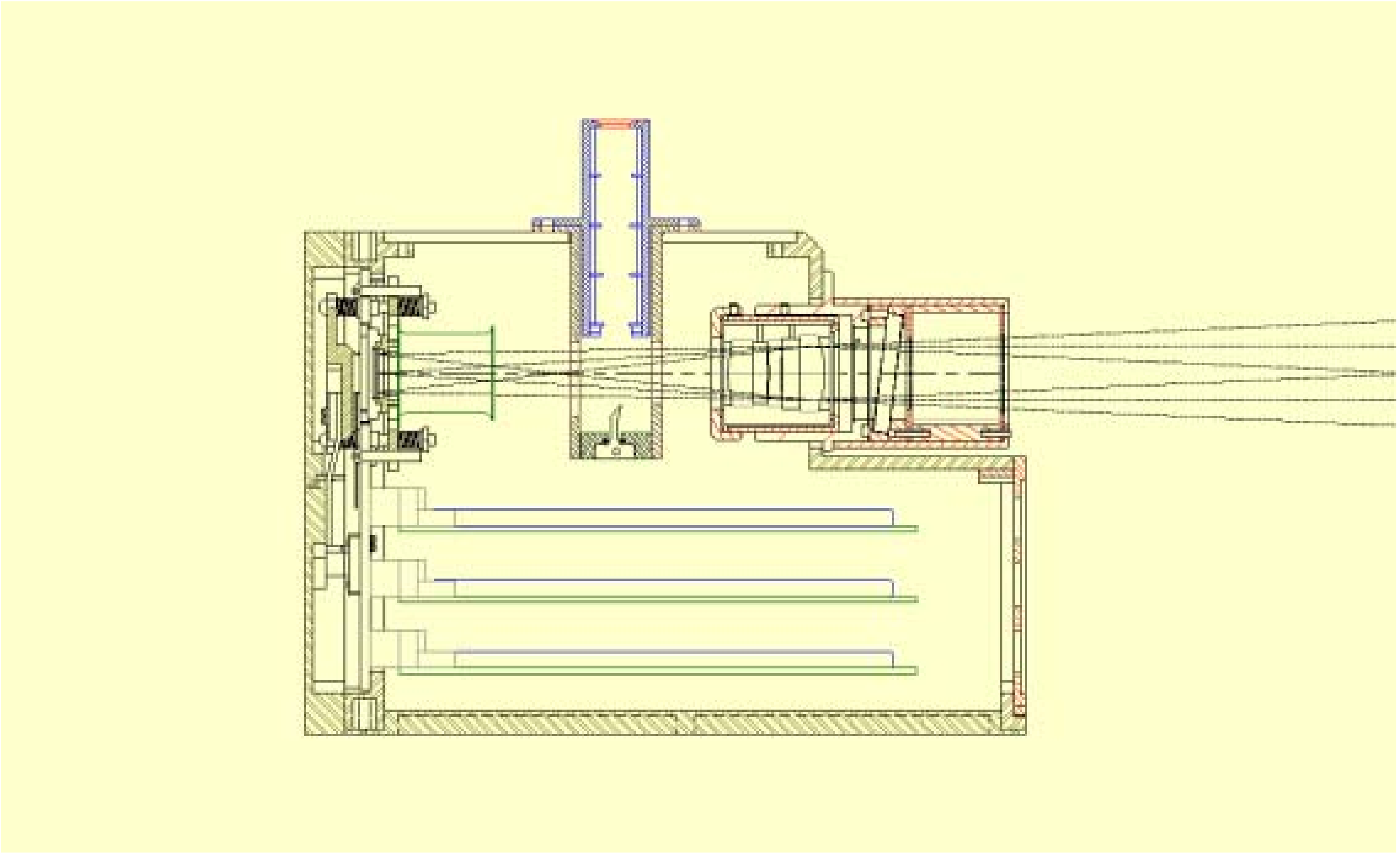
Wedged Filter Schematic



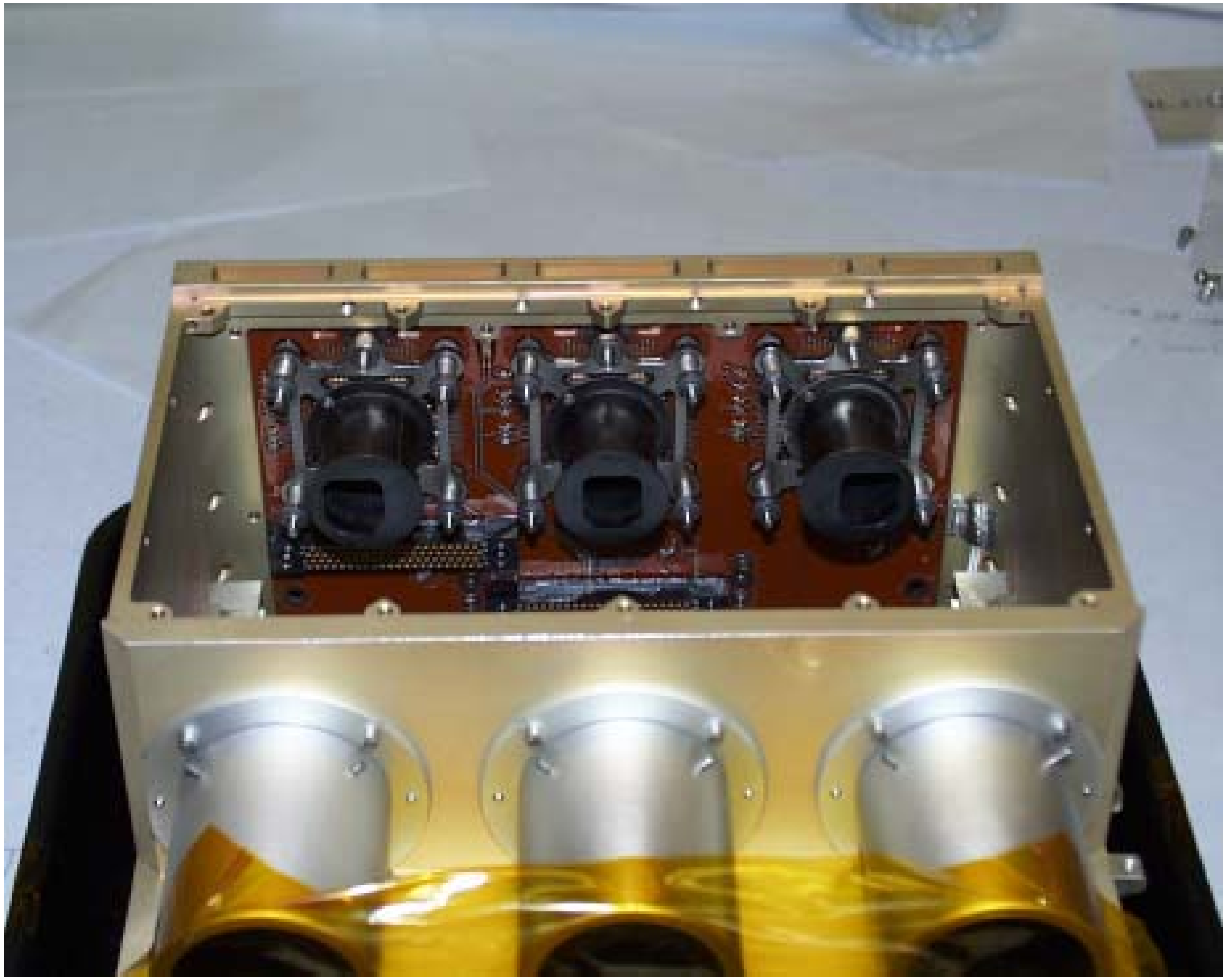
Filter Layer Composite Detail



Optics Module Detail



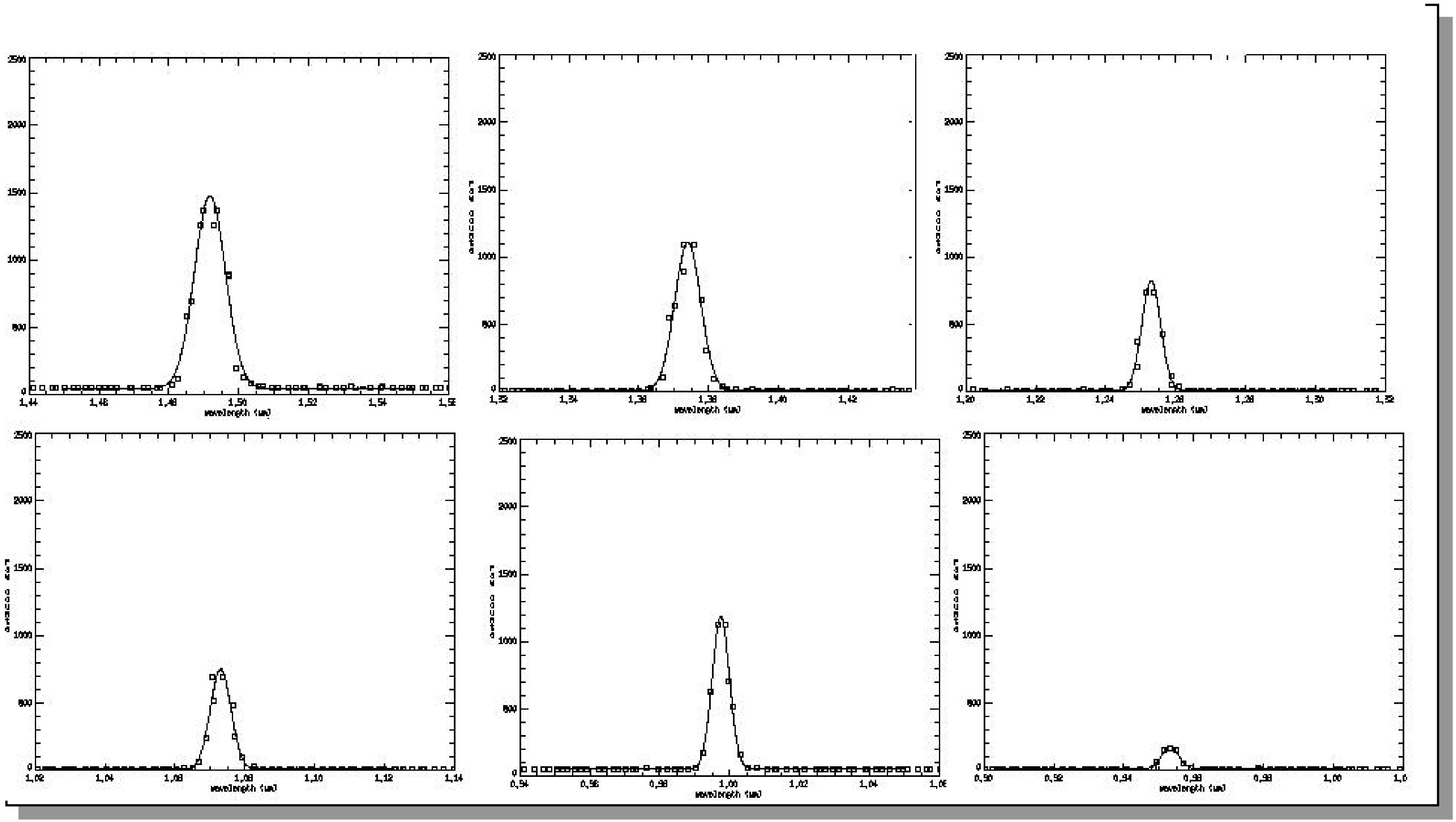
LAC Internal Detail



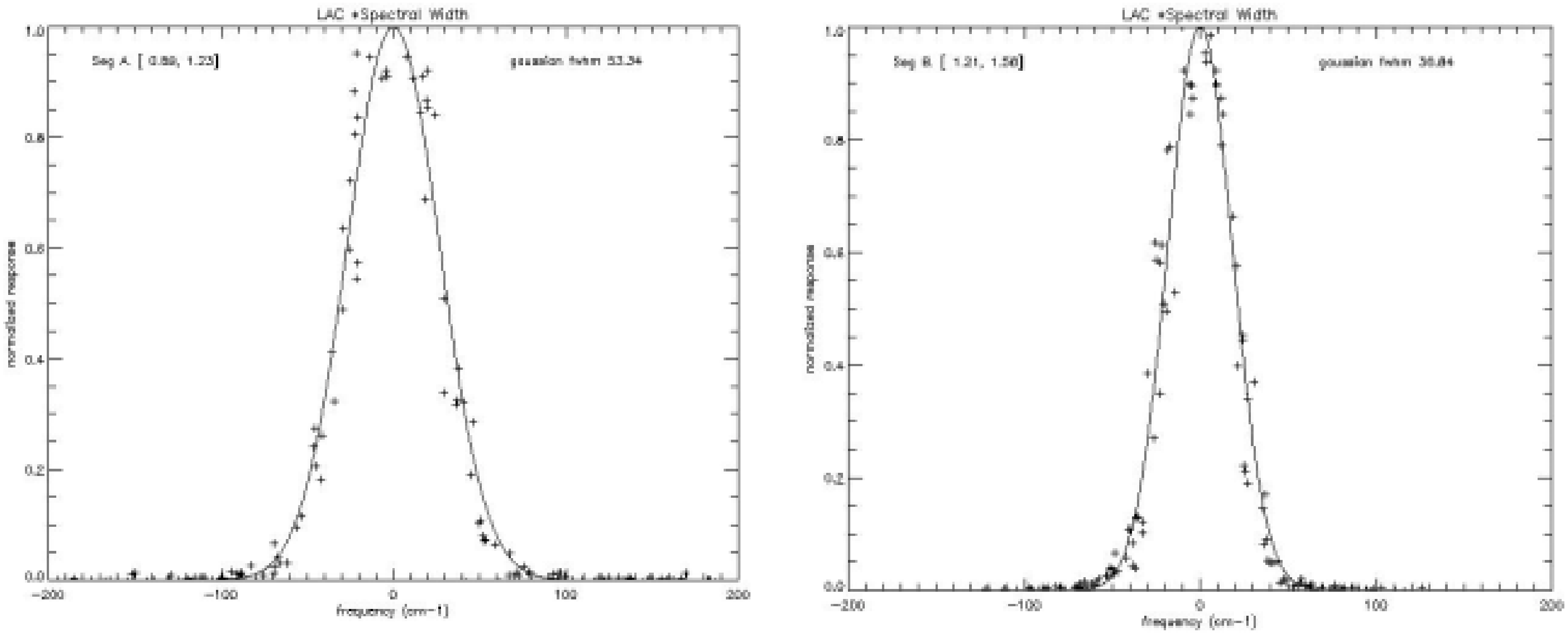
LAC Performance

- ***Spectral Coverage: ~0.9 - 1.6 μm; 256 Bands Selected for Optimal Correction of High Spatial Resolution Images.***
- ***Spectral Resolution 2 Filter Sections:***
  Section 1 ~35 cm^{-1} ($\Delta\lambda$: 5 nm @ 1.2 μm, 9 nm @ 1.6 μm)
  Section 2 ~55 cm^{-1} ($\Delta\lambda$: 4 nm @ 0.9 μm, 8 nm @ 1.2 μm)
- ***Swath Width: ~185 km; Matches Landsat***
- ***Spatial Resolution (pixel): 356 μradian (250 meter @ 705 Km).***
- ***Three 256 x 256 Element InGaAs Arrays; TEC Stabilized (<285 K).***
- ***Three 15 Degree FOV 3 Element Lenses***
- ***Two Modules: "Bolt-on" Optics Module and Electronics Module.***
- ***Mass: 10.5 kg (EM, 4.4 kg; OM 3.9 kg; Cable 2.2 kg)***
- ***Power: 48 W (Peak); <15 W (Orbital Average)***

LAC Line Widths



LAC Half-Width Summary



LAC System Trades

- ***Spatial Resolution vs. Spatial Coverage***
  - *250 meter spatial resolution near maximum required for atmospheric correction*
  - *185 km Matches Landsat7*
  - *Requires three 256 x 256 arrays*
- ***Thermo-Electric Coolers (TEC) vs. Passive Radiators***
  - *TECs require more power, but significantly simplify integration and operations*
- ***Wedged Filter vs. Conventional Technologies***
  - *Wedged filter data Analysis systems not as developed but instrument has less mass and complexity than conventional*
  - *No moving parts*

LAC System Trades

- ***IR vs. Visible Spectral Coverage***
  - *IR gives better water vapor and cirrus cloud information at the expense of aerosol information*
  - *InGaAs arrays now can cover 0.5 to 1.7 micron*
- ***1.6 vs. 2.5 micron Longwave Cutoff***
  - *Cryogenic cooling not required*
- ***Two Module vs. 1 Module Design***
  - *Gain in system flexibility and platform independence compensates for increased mass and additional integration*

LAC Performance Testing

- ***Box Level***
  - ***All Cards Simulated on an Individual Basis***
  - ***TECs Tested with Engineering Backplane (Focal Plane)***
  - ***Focal Plane Timing Tested with Multiplexers***
- ***Subsystem Level***
  - ***OM: Limited Set of Images Obtained with EM Simulator***
    - *Engineering Model Vibration Tested*
  - ***EM: Operation Tested by Interface to OM Simulator***
- ***Instrument Level***
  - ***Vibration and Thermal-Vacuum***
  - ***Radiometric/ Spectral Calibration and Alignment***
  - ***EMI/EMC***

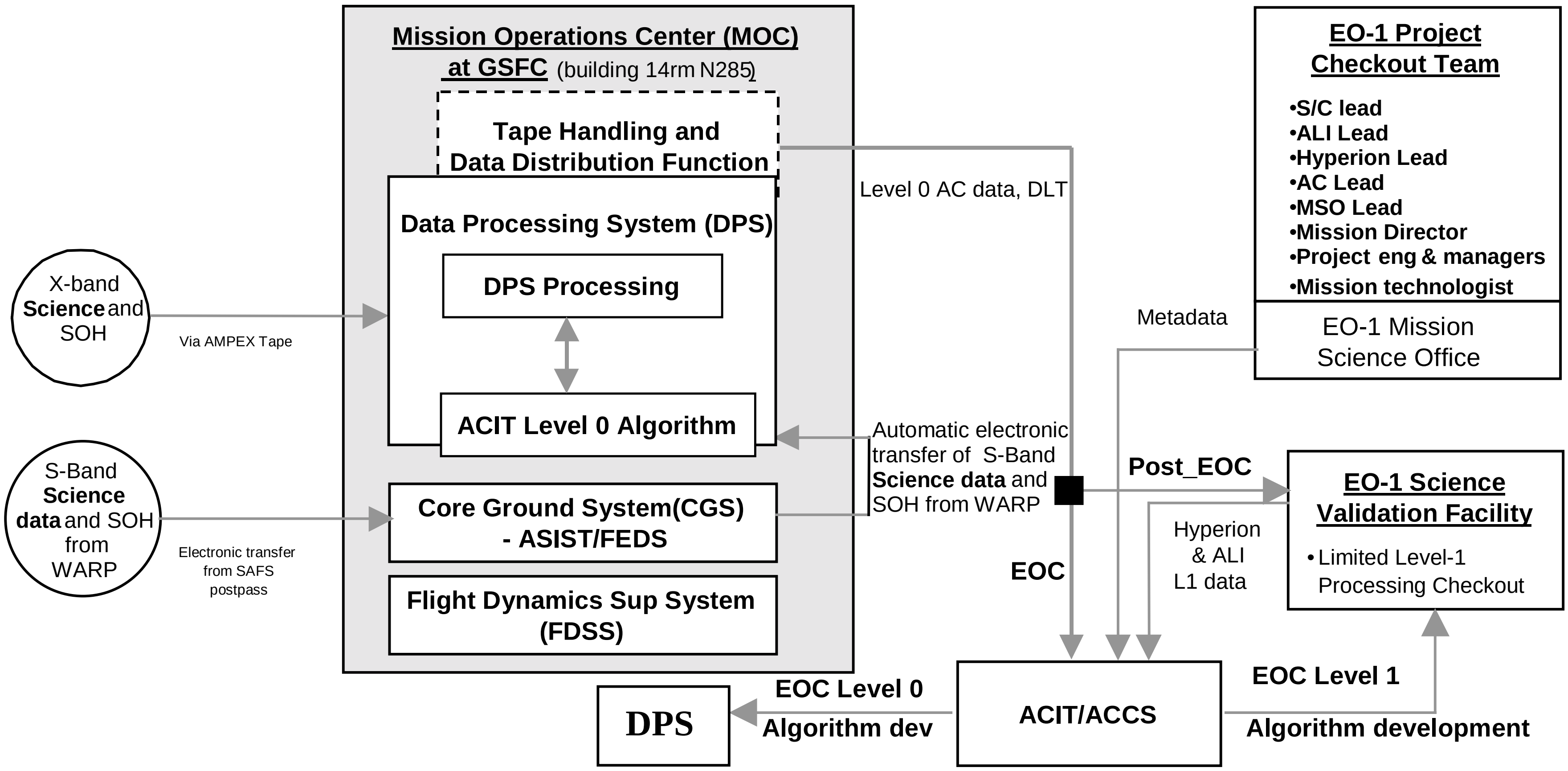
LAC Test Descriptions

- ***Vibration:***
  - *Individual Modules Tested to Proto-flight Level (1.25 X Expected Maximum Flight Loads)*
  - *Instrument Mounted on Spacecraft and Tested to Flight Level*
- ***Thermal Vacuum (Pre-spacecraft Integration):***
  - *Four Cycles to Survival Levels (-10° C to + 50° C; Range Expected on Orbit 20° C ± 10° C)*
  - *Operation from 0° C to 30° C (Orbital Predict 20° C, 30° C Worst Case)*
  - *Images Obtained Using LAC GSE*
- ***Thermal Vacuum (Integrated with Spacecraft):***
  - *Four Cycles*
  - *Operation from 0° C to 30° C (No Operation at 40° C)*
  - *Images Using Spacecraft System (WARP, XPAA, etc.)*

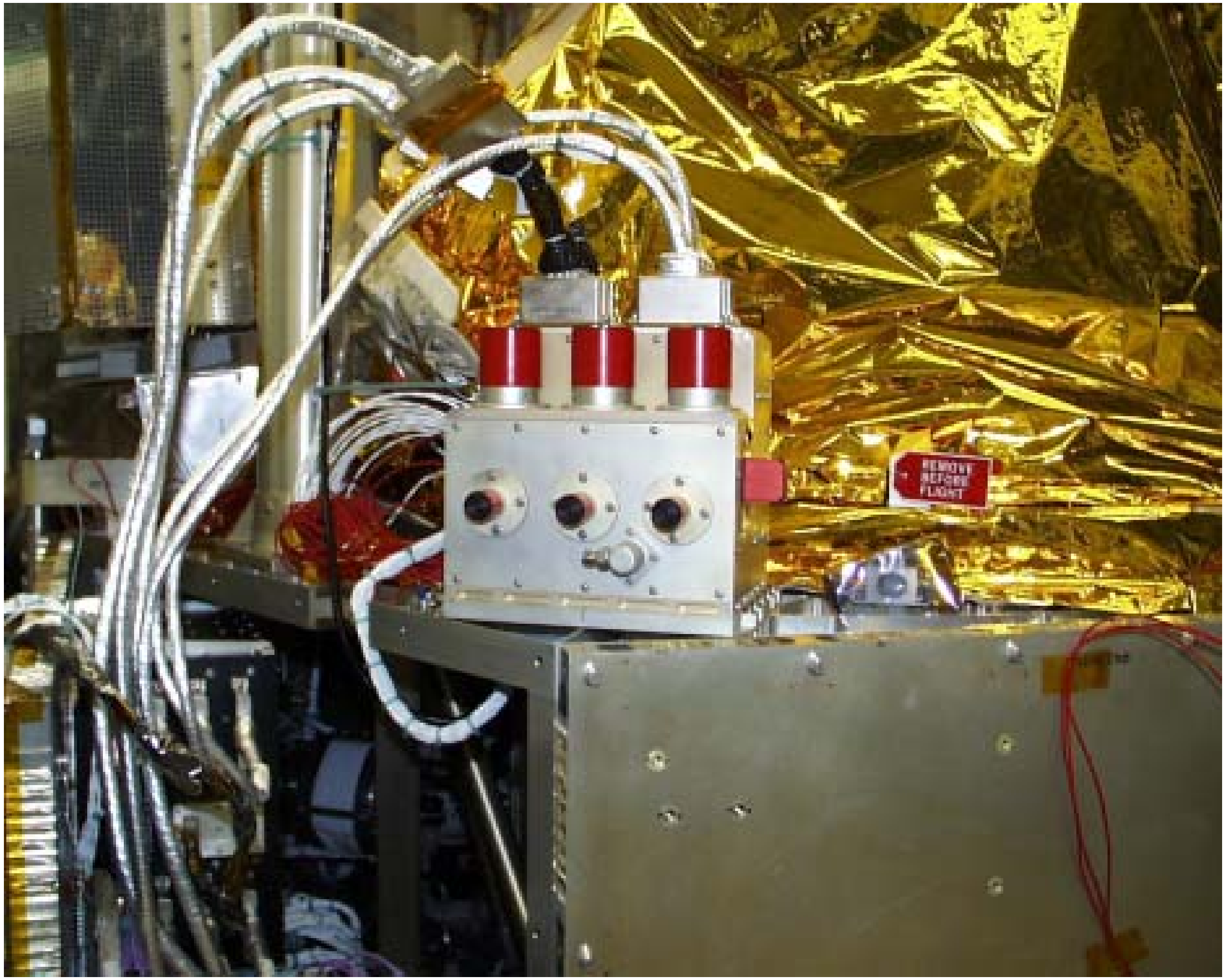
LAC Test Descriptions

- ***EMI/EMC:***
  - *Instrument Level Tests: Conducted and Radiated Emissions, and Radiated Susceptibility*
- ***Alignment:***
  - *Orientation of Arrays with respect to Alignment Cube Using Theodolites*
  - *LAC Alignment to ALI on Spacecraft Using Theodolites*
- ***Optical Calibration:***
  - *Wavelength and Instrumental Shape: Grating Monochrometer 1 to 100 nm Steps*
  - *Radiometric: Calibrated Black-body (all 4 TEC Settings)*
  - *Flat Field: Diffuse Source Illuminating Lenses and Solar Calibrators*

Data Flow

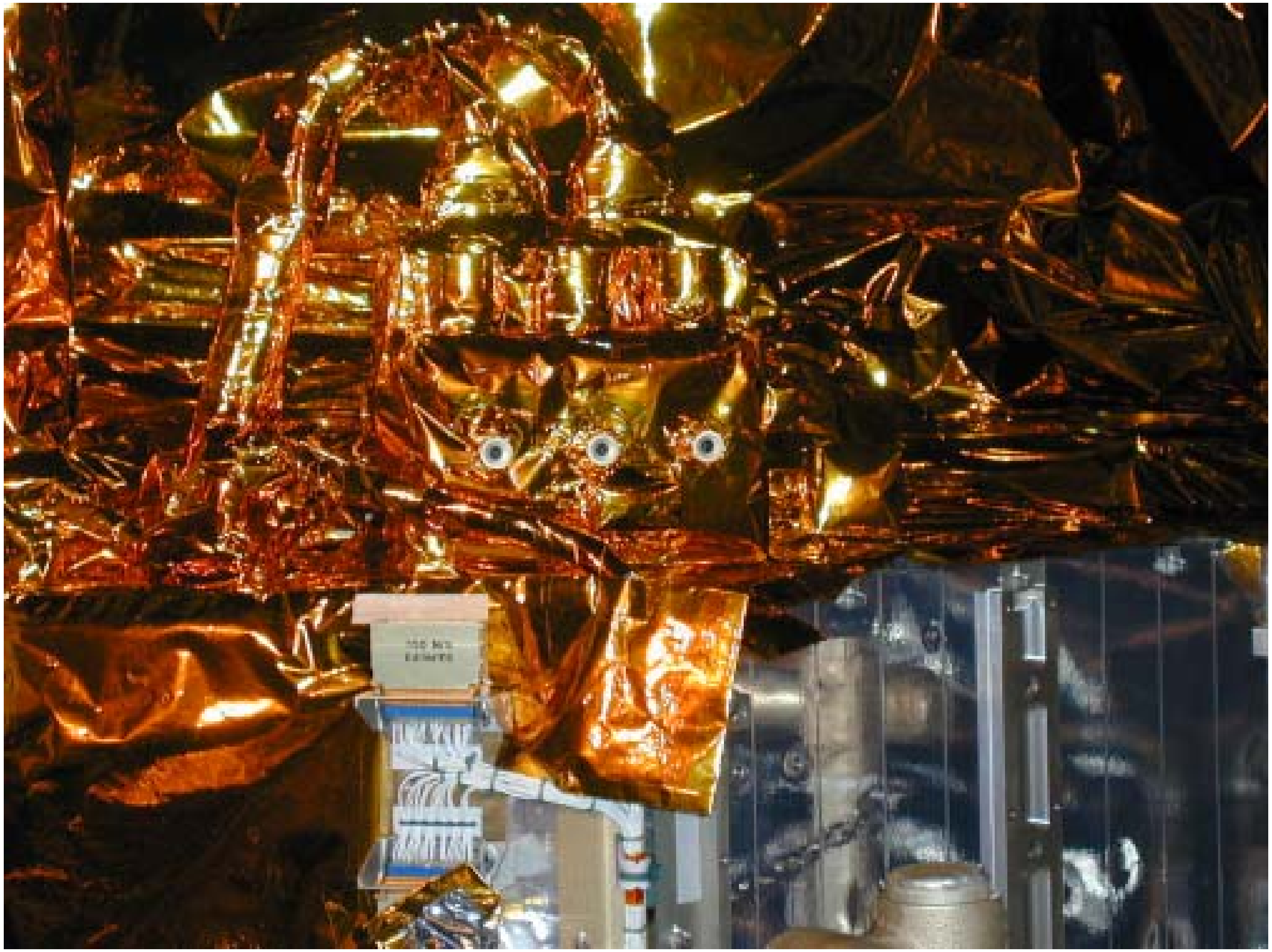

Mission Operations Center (MOC) at GSFC (building 14rm N285)
Tape Handling and Data Distribution Function
Data Processing System (DPS)
DPS Processing
ACIT Level 0 Algorithm
Core Ground System(CGS) - ASIST/FEDS
Flight Dynamics Sup System (FDSS)
X-band Science and SOH
Via AMPEX Tape
S-Band Science data and SOH from WARP
Electronic transfer from SAFS postpass
Level 0 AC data, DLT
Automatic electronic transfer of S-Band Science data and SOH from WARP
EO-1 Project Checkout Team
•S/C lead
•ALI Lead
•Hyperion Lead
•AC Lead
•MSO Lead
•Mission Director
•Project eng & managers
•Mission technologist
EO-1 Mission Science Office
Metadata
Post_EOC
EO-1 Science Validation Facility
• Limited Level-1 Processing Checkout
Hyperion & ALI L1 data
EOC
ACIT/ACCS
DPS
EOC Level 0 Algorithm dev
EOC Level 1 Algorithm development

LAC on Spacecraft



- ***Atmospheric Corrector on EO-1***
- ***Three lenses are nadir facing***
- ***Solar Calibrators are facing forward***
- ***Alignment cube on right***

LAC Pre-Launch

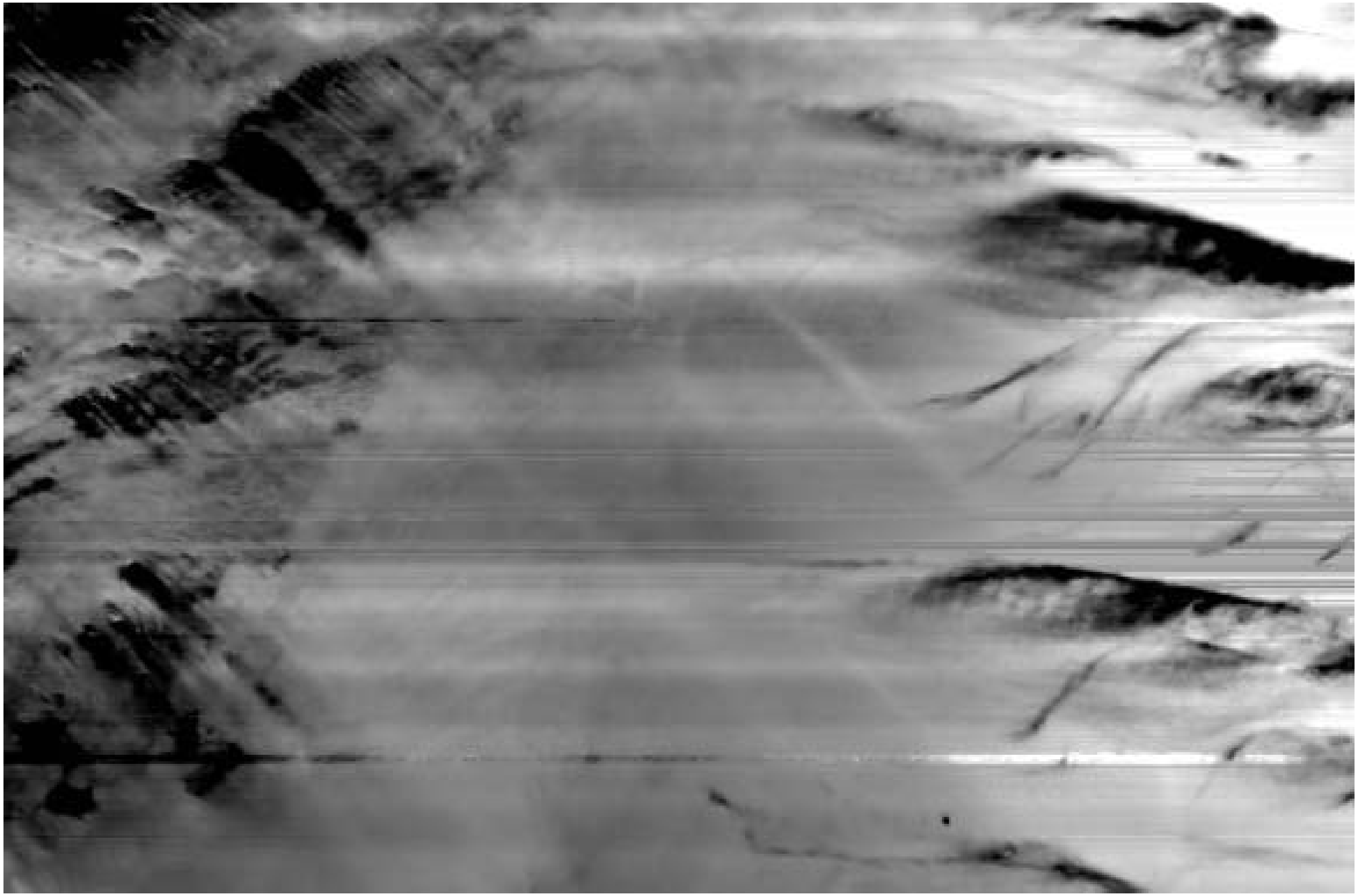


LAC Comparative Size

LAC Technology Transfer

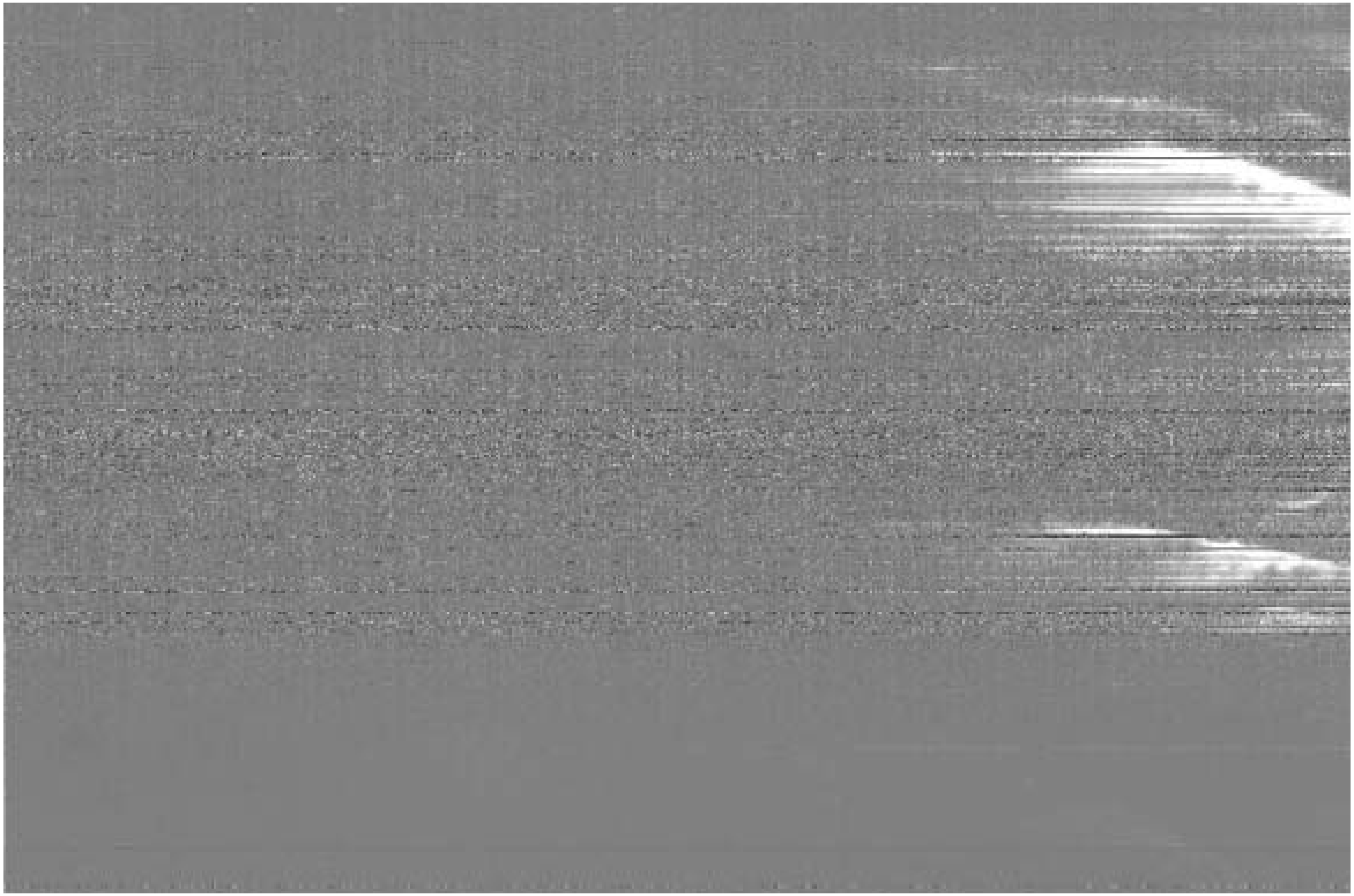
- *Compact design adaptable to many moderate Spatial Resolution Hyperspectral applications*
- *Optics Module adaptable to redesign for differing spatial resolutions*
- *Electronics Module adaptable to redesign for differing spacecraft interfaces*
- *Spectral coverage/spectral resolution selectable by choice of Wedged Filter*
  - *0.5 to 1.7 μm InGaAs Arrays Available*
- *GSFC owns this design and is willing to infuse it into any U.S. commercial or academic institution*

LAC Image of Niger3 (1.243 μm)

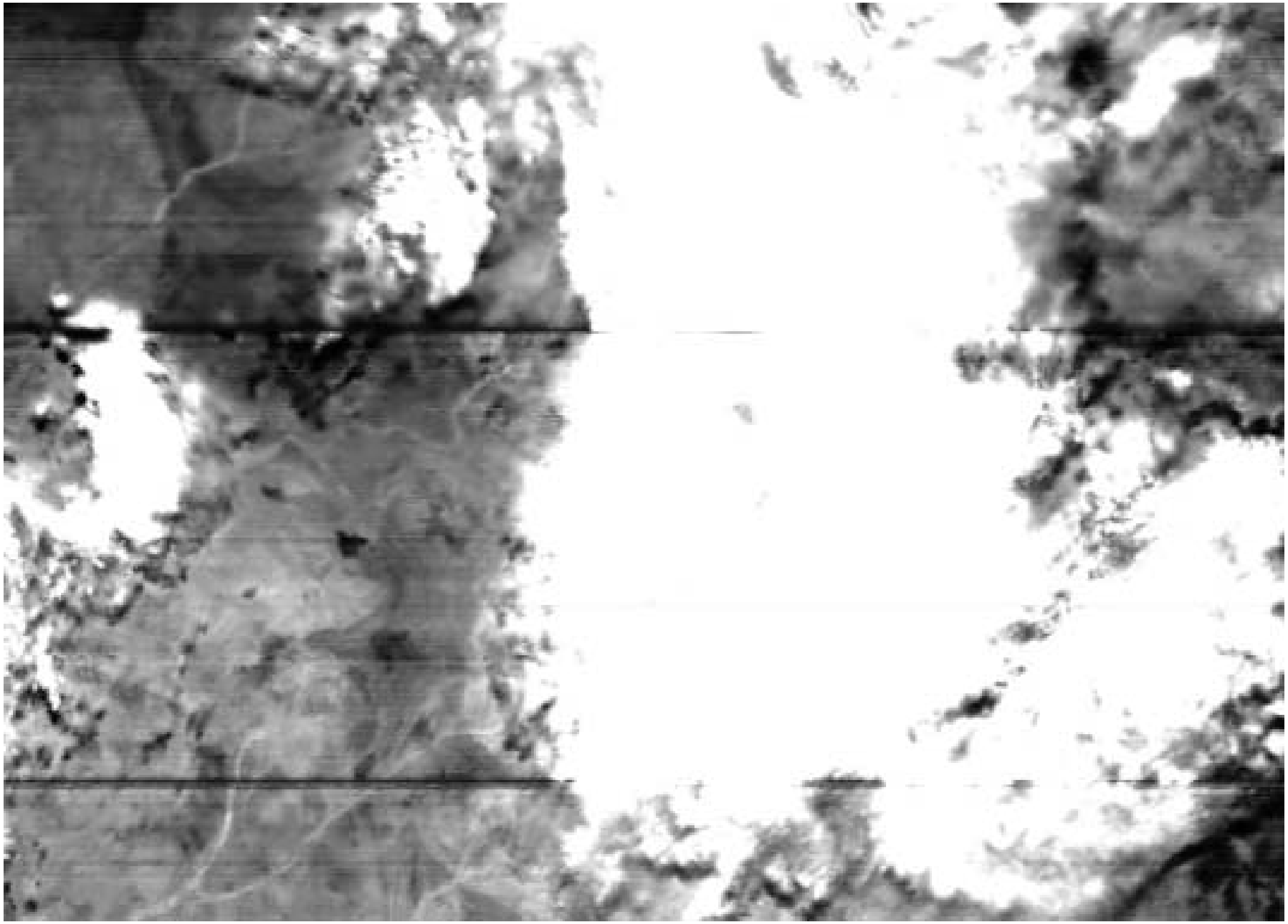


Landsat Image of Niger3

LAC Image of Niger3 (1.383 μm)



LAC Image of Panorama (1.243 μm)



Landsat Image of Panorama

Section 8

Science Validation Process

Science Validation Team

- ***Instrument Team***
  - *Validate/re-establish and refine pre-launch characterizations*
  - *Provide technology validation*
  - *Participate on Science Validation Team*
- ***NASA Selected Investigators***
  - *Conduct scene based instrument performance characterizations*
  - *Measure ability of instruments to make Landsat-like observations*
  - *Assess capability for addressing earth remote sensing applications*
  - *Assist in technology validation*
  - *Facilitate Commercial Applications (CRSP/SSC)*
- ***International Collaborators***
  - *Argentina, Australia, Canada, Italy, Japan, Singapore*

If scientists supply accurate and reliable information, policy makers can make intelligent and responsible decisions to preserve an acceptable quality of life for our children and grandchildren.

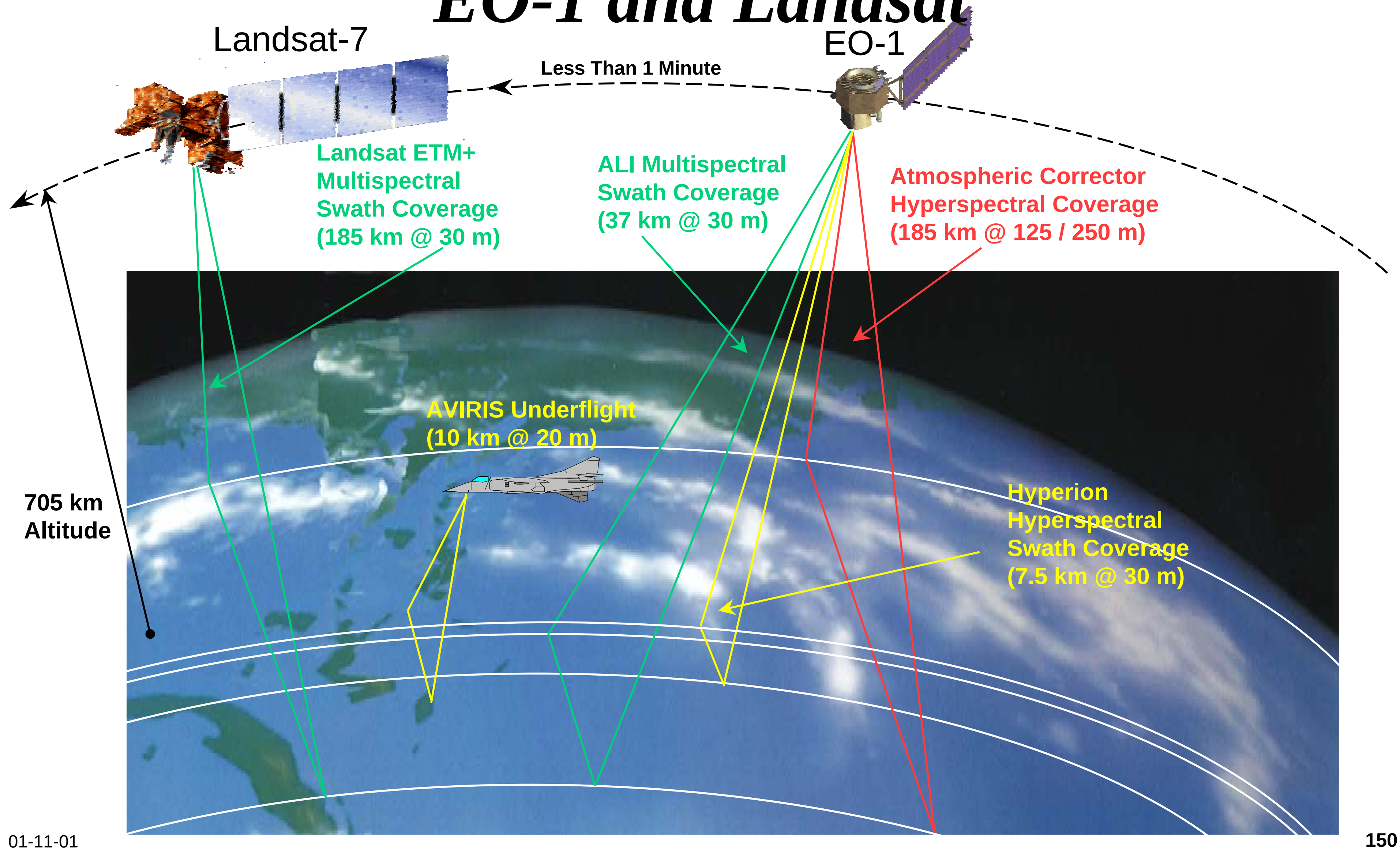
Characterization & Validation

- ***Characterization** quantitatively describes how the three EO-1 instruments respond to incident radiation (light) under a variety of operating conditions.*
- ***Validation** assesses the EO-1 instrument measurements by comparing them against ground "truth". We also assess performance.*

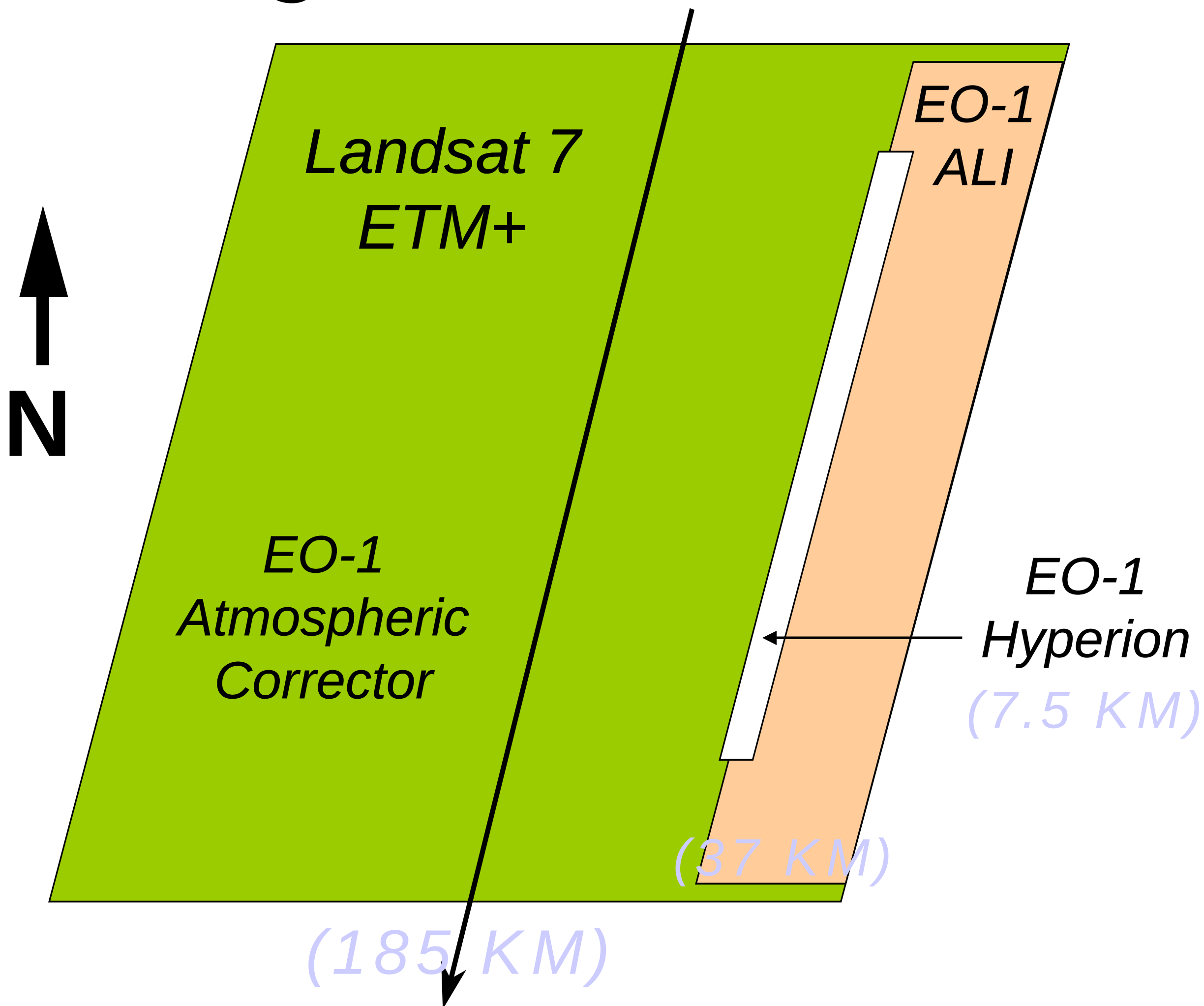
What's So Exciting About Calibration?

- ***Calibration is the stuff you do to insure accurate and repeatable measurements with the EO-1 instruments***
  Ho hum!
- ***Calibration can be used to provide a common basis for inter-comparing global measurements across a variety of earth satellite observing systems with profound ramifications!***

EO-1 and Landsat



EO-1 and Landsat 7 Descending Orbit Ground Tracks



EO-1 Instrument Overviews

Parameters	Landsat 7 ETM+	EO-1 ALI Multispectral	EO-1 HYPERION	EO-1 AC
Spectral Range	0.4 - 2.4 µm *	0.4 - 2.4 µm	0.4 - 2.5 µm	0.9 - 1.6 µm
Spatial Resolution	30 m	30 m	30 m	250 m
Swath Width	185 Km	37 Km	7.5 Km	185 Km
Spectral Resolution	Variable	Variable	10 nm	3 - 9 nm **
Spectral Coverage	Discrete	Discrete	Continuous	Continuous
Pan Band Resolution	15 m	10 m	N/A	N/A
Total Number of Bands	7	10	220	256

** Excludes thermal channel*
*** 35 cm^{-1} constant resolution*

EO-1 Instrument Overviews

Parameters	Landsat 7 ETM+	EO-1 Multispectral	EO-1 HYPERION	EO-1 AC
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Pan Band Resolution	15 m	10 m	N/A	N/A
Total Number of Bands	7	10	220	256

** Excludes thermal channel*
*** 35 cm^{-1} constant resolution*

Hyperspectral Analysis derives from the use of contiguous spectral channels, allowing the use of derivatives and sophisticated analysis techniques. The large number of bands allows more complex systems to be addressed without the under sampling inherent in multispectral systems.

Investigator Research Topics

Research Topic	Principal Investigator
Forest Logging in Amazonia	**Asner, G. P.,** University of Colorado
Desertification	**Asner, G. P.,** University of Colorado
Forest Composition & Function	**Martin, M.,** University of New Hampshire
Inter-Sensor Calibration	**Huete, A. R.,** University of Arizona, Tucson
Arid Vegetation Abundance	**Mustard, J. F.,** Brown University.
Tropical Forest Burn Scars	**Liew, S. C.,** National University of Singapore
Forest Composition/Structure	**Townsend, P. A.,** University of Maryland
Land Cover/Land Use	**White, W. A.,** University of Texas at Austin
Sustainable Forest Development	**Goodenough, D. G.,** Natural Resources Canada
Monitoring Forest & Rangeland	**Gong, P.,** University of California, Berkeley
Non-Native Plant Species	**McGwire, K.** Desert Research Institute

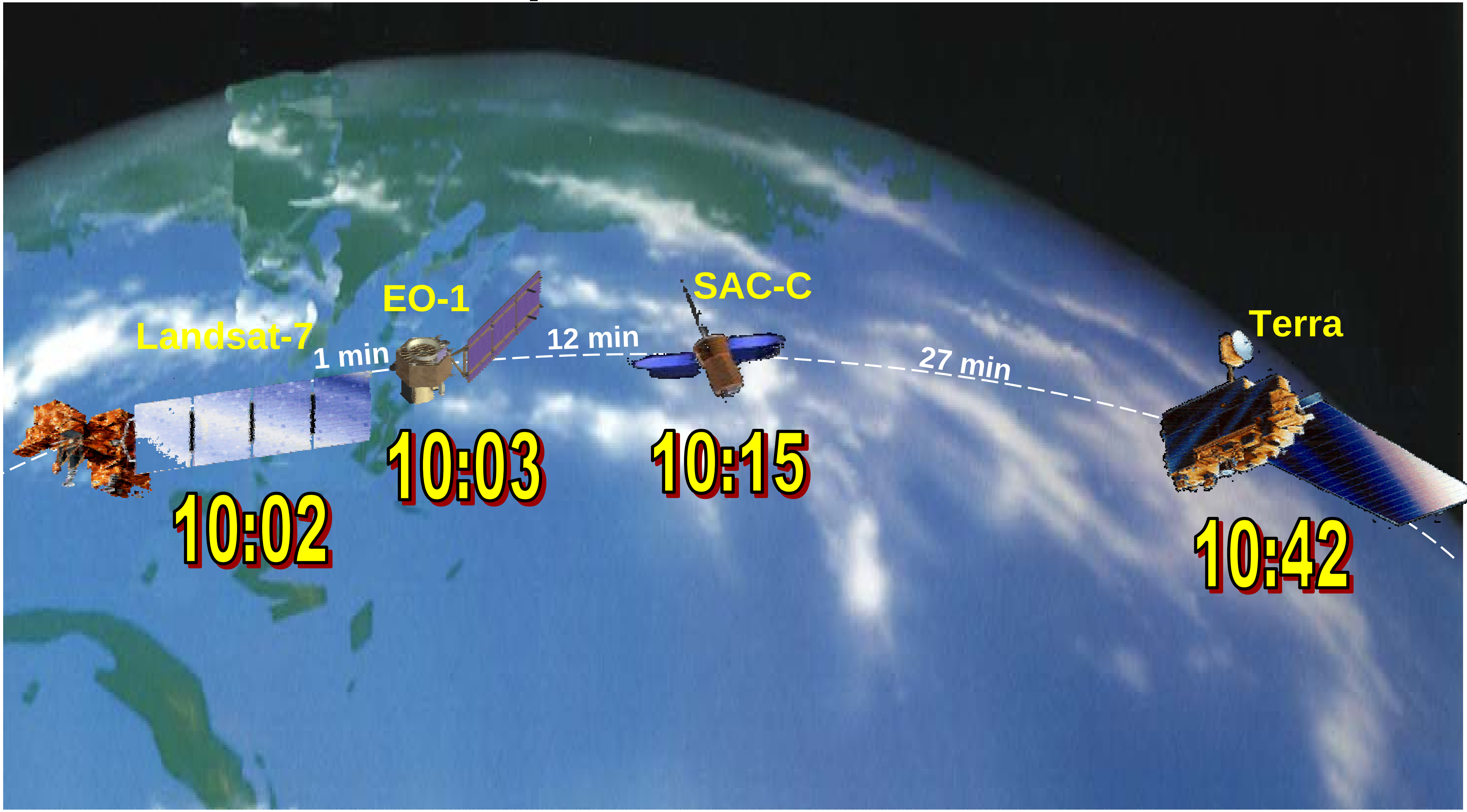
Investigator Research Topics (continued)

Research Topic	*Principal Investigator*
Invasive Plants: Chinese Tallow	***Ramsey III, E. W.,*** *USGS, Denver*
Invasive Leafy Spurge	***Root, R.,*** *USGS*
Agricultural Monitoring	***Liang, S.,*** *USDA, Maryland*
Inter-Satellite Comparison	***Moran, M. S.*** *USDA, Tucson, Arizona.*
Fire Hazard Assessment	***Roberts, D. A.,*** *University of California, Santa Barbara*
Geologic Validation of Hyperion	***Kruse, F. A.,*** *AIG, Boulder, Colorado*
Volcanic Debris flow Hazards	***Crowley, J. K.,*** *USGS, Reno, Nevada*
Analysis of Hot Spots	***Flynn, L.,*** *University of Hawaii.*
Environmental Monitoring of Coastal/Inland Water in Japan	***Matsunaga, T.,*** *Tokyo Institute of Technology.*
Oceanography, Pollution and Urban Mapping	***Abrams, M. J.,*** *JPL, California;* ***R. Bianchi and L. Alberotanza,*** *NRC, Italy.*
Glaciological Applications	***Bindschadler, R.,*** *NASA/GSFC, Maryland*

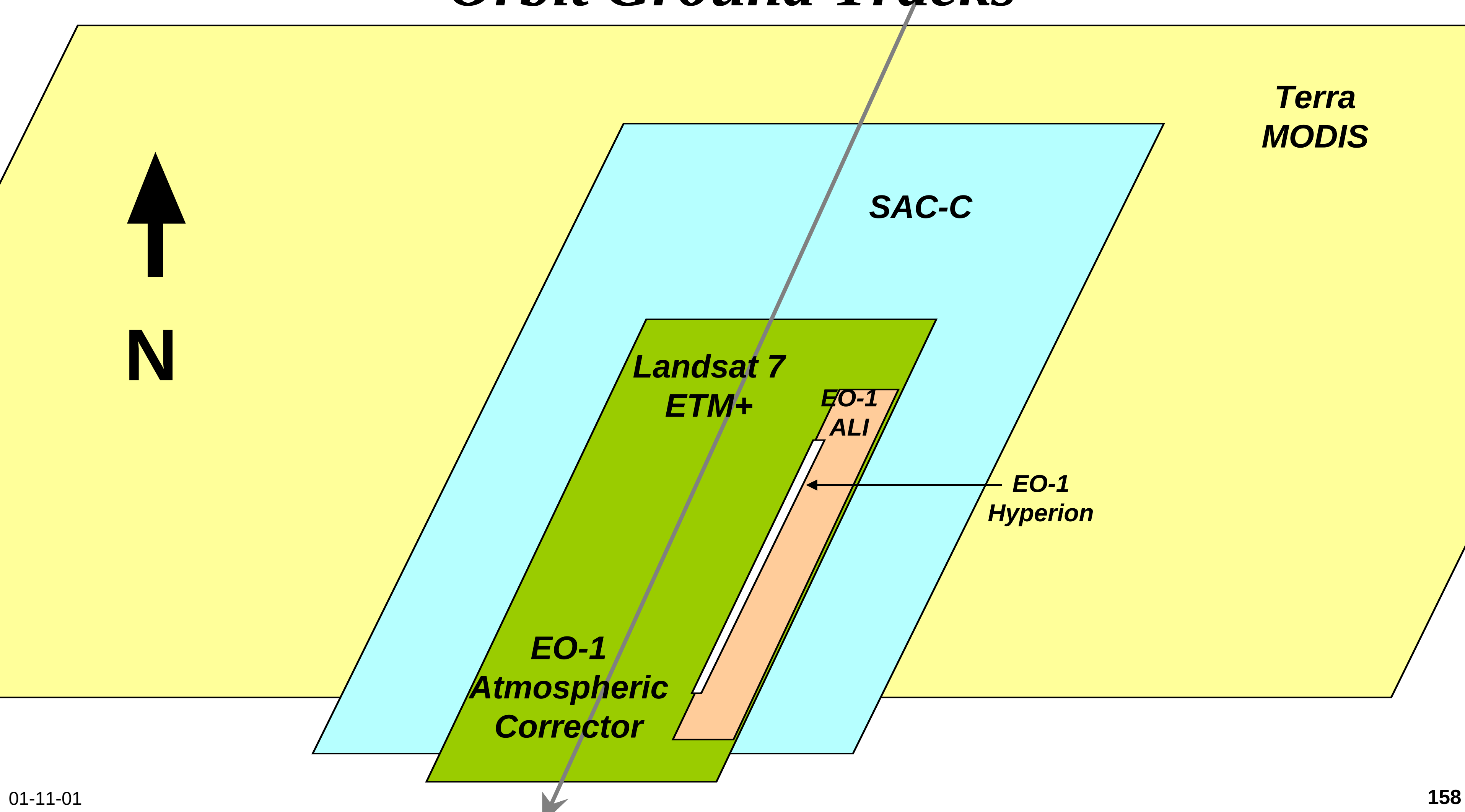
Investigator Research Topics (continued)

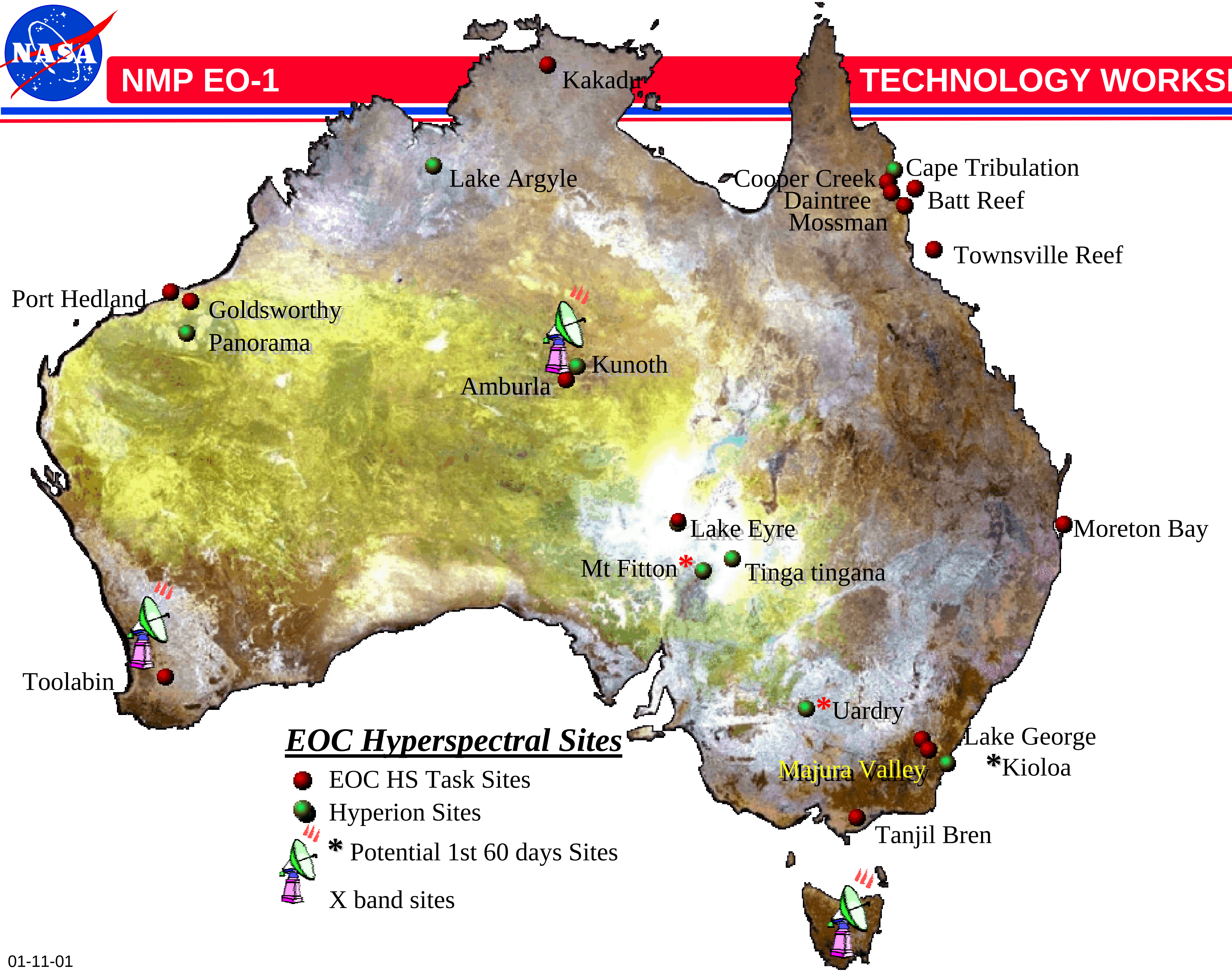
Research Topic	*Principal Investigator*
Ecological Applications in Yellowstone National Park	***Boardman, J. W., AIG,*** *Colorado*
Commercial Applications	***Cassady, P. E.,*** *Boeing, Washington*
Radiometric and Spatial Evaluation of ALI and Hyperion	***Biggar, S. F.,*** *University of Arizona*
Atmospheric Correction	***Carlson, B. E.,*** *NASA /GISS, New York*
Atmospheric Correction and Sparse Vegetation Mapping	***Goetz, A. F. H.,*** *University of Colorado*
Australian Hyperspectral Calibration and Validation Sites	***Jupp, D. L. B.,*** *CSRIO, Australia*
Integrated Assessment of EO-1 and Landsat Instrument Suites	***Meyer, D. J.,*** *EDC, South Dakota*
Canopy Temperature Estimation	***Smith, J. A.,*** *NASA GSFC, Maryland*
Lunar Calibration	***Kieffer, H.,*** *USGS, Flagstaff, AZ*

The EOS AM Constellation Alignment for March, 2001



AM Constellation Descending Orbit Ground Tracks

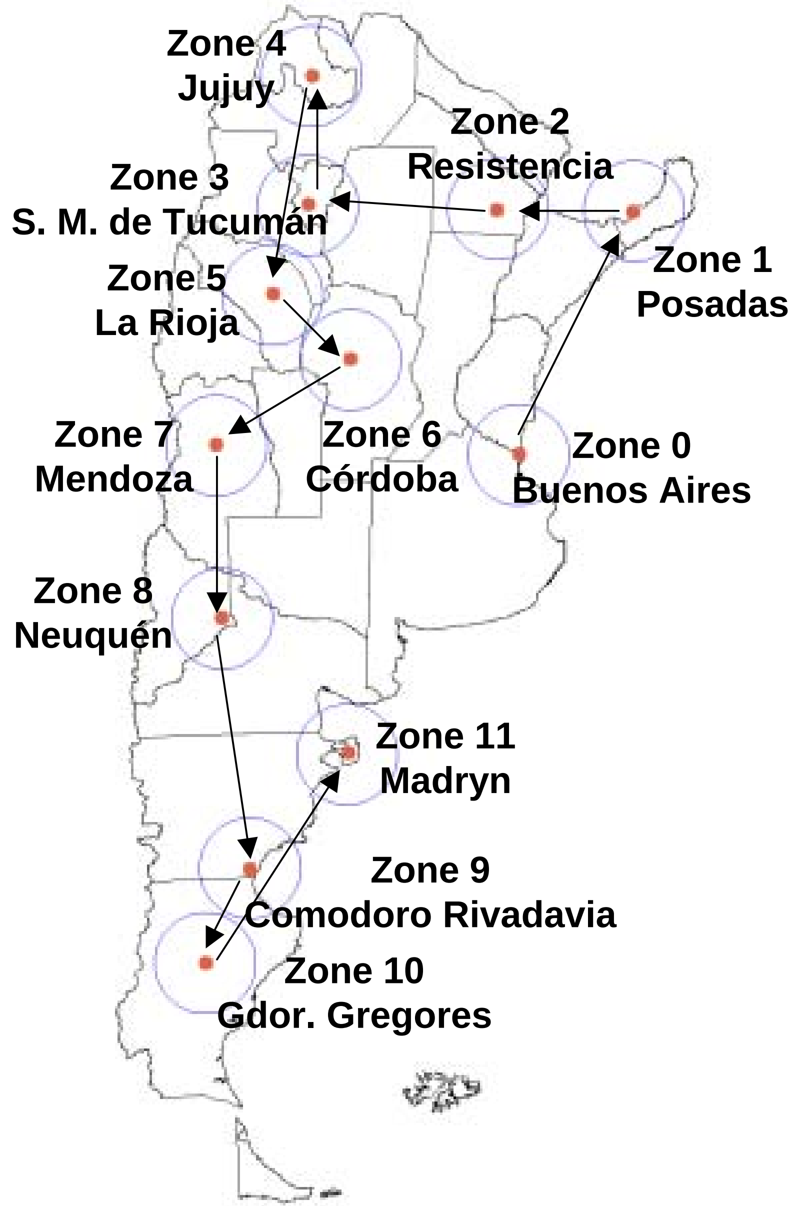



Kakadu
Lake Argyle
Cooper Creek
Daintree
Mossman
Cape Tribulation
Batt Reef
Townsville Reef
Port Hedland
Goldsworthy
Panorama
Kunoth
Amburla
Lake Eyre
Mt Fitton*
Tinga tingana
Moreton Bay
Toolabin
*Uardry
Lake George
Majura Valley
*Kioloa
Tanjil Bren
EOC Hyperspectral Sites
EOC HS Task Sites
Hyperion Sites
* Potential 1st 60 days Sites
X band sites


CSIRO
Earth Observation Centre
Tinga Tingana Cal_Val Site

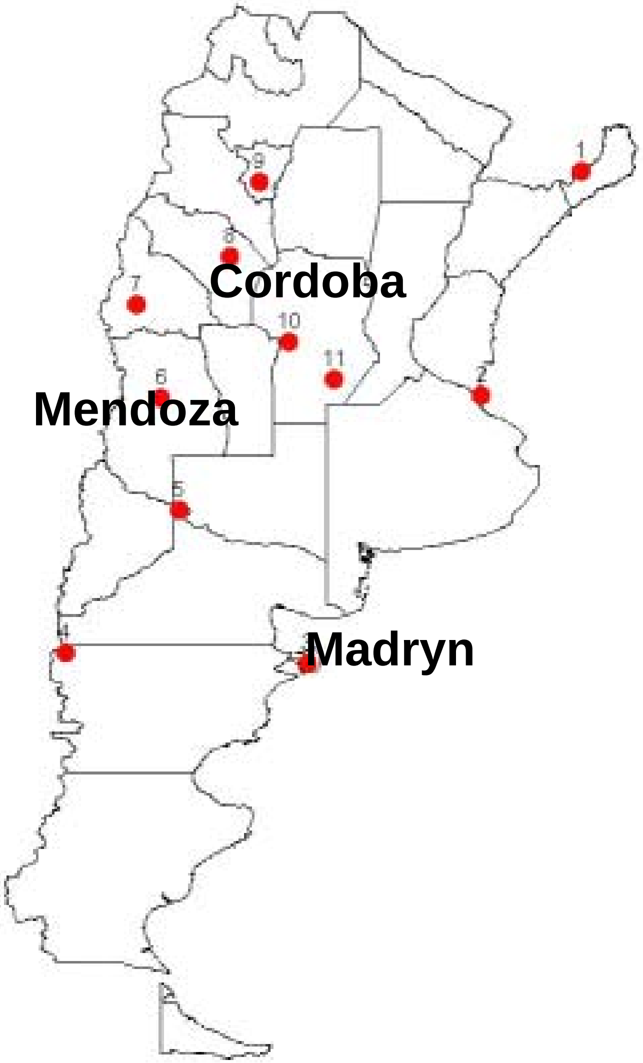
Argentina Validation Site Zone Map

for AVIRIS and EO-1/SAC-C overflights

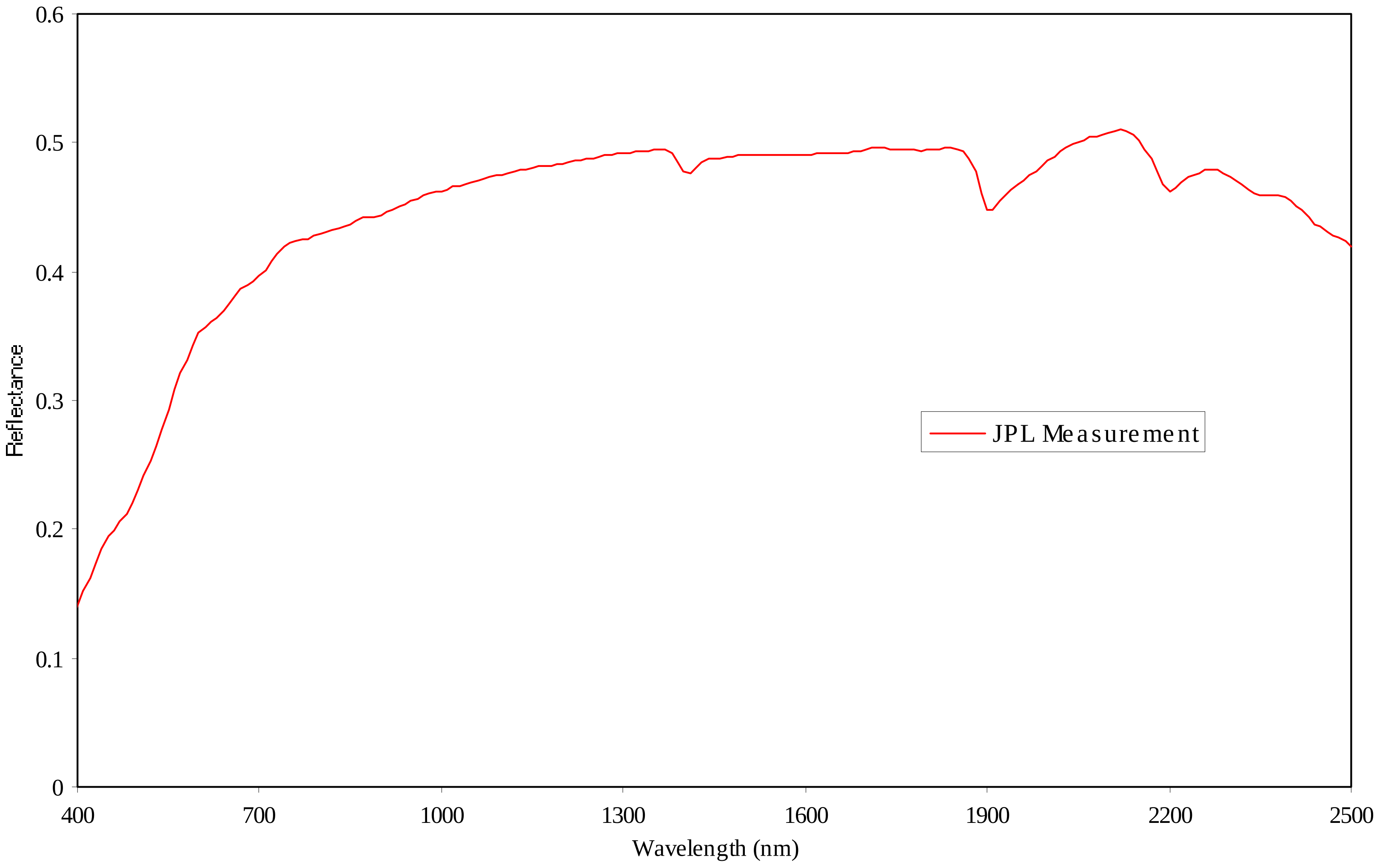


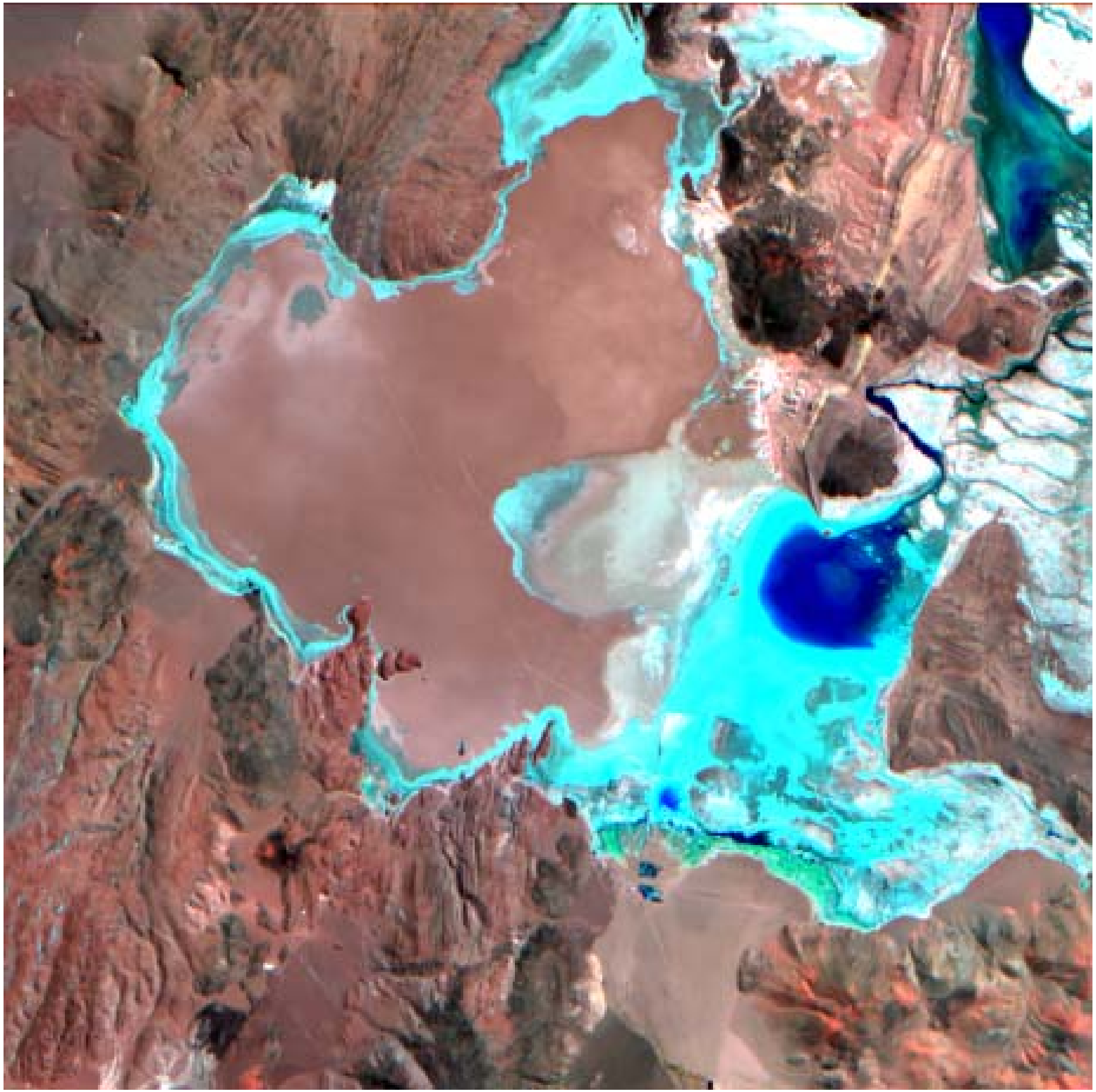
Zone	#	Flight Line Name	Start Lat	min	Start Lon	min	End Lat	min	End Lon	min	Hours
0) Buenos Aires	1	pergamino-v	-33	53.580	-60	34.020	-34	3.000	-60	34.020	2.5
	2	Pergamino-h	-33	58.020	-60	39.000	-33	58.020	-60	28.980	0.5
	3	Capital Federal-1	-34	32.000	-58	26.000	-34	40.500	-58	31.500	0.5
	4	Capital Federal-2	-34	41.330	-58	30.000	-34	33.000	-58	24.000	0.5
	5	Delta	-34	22.020	-58	1.980	-34	13.020	-58	24.000	0.5
	6	Magdalena	-34	58.980	-57	35.760	-35	7.020	-57	24.360	0.5
		TRANSIT									4.0
1) Posadas	1	Libertad	-25	55.320	-54	37.560	-25	56.230	-54	18.480	0.5
	2	Eldorado 1	-26	19.610	-54	38.550	-26	34.770	-54	41.230	0.5
	3	Eldorado 2	-26	20.730	-54	40.710	-26	35.810	-54	43.450	0.5
	4	Oberá 1	-27	17.280	-55	17.450	-27	25.810	-55	13.200	0.5
	5	Oberá 2	-27	17.250	-55	6.800	-27	32.650	-55	5.010	0.5
	6	Iberá	-28	3.000	-56	49.980	-28	5.520	-57	0.480	1.0
		TRANSIT									4.0
2) Resistencia	1	Campo del Cielo 1	-27	31.020	-61	34.980	-27	45.000	-61	49.020	0.5
	2	Campo del Cielo 2	-27	2.280	-61	17.916	-27	29.646	-61	39.282	0.5
	3	Campo del Cielo 3	-27	30.636	-61	38.772	-27	23.286	-61	17.670	0.5
	4	Santiago del Estero 1	-27	24.264	-61	17.058	-27	31.530	-61	38.370	0.5
	5	Santiago del Estero 2	-27	32.682	-61	37.902	-27	25.284	-61	16.764	0.5
	6	Chaco	-27	26.310	-61	16.314	-27	33.684	-61	37.482	0.5
		TRANSIT									6.0
3) Tucumán	1	San Miguel	-27	0.000	-65	34.980	-27	10.020	-65	25.020	4.5
	2	Monteros	-27	0.000	-65	6.000	-26	28.020	-65	18.000	0.5
	3	Farallon Negro 1	-27	21.660	-66	38.350	-27	15.520	-66	33.180	0.5
	4	Farallon Negro 2	-27	19.620	-66	25.920	-27	25.430	-66	17.500	0.5
	5	Farallon Negro 3	-27	20.880	-66	29.920	-27	19.620	-66	25.920	0.5
		TRANSIT									4.0
4) Jujuy	1	Arizaro 1	-24	50.000	-67	42.000	-25	10.000	-67	42.000	2.5
	2	Arizaro 2	-24	58.000	-67	30.000	-24	58.000	-67	50.000	1.0
	3	Arizaro 3	-25	0.000	-67	48.000	-25	10.000	-67	38.000	1.0
	4	Arizaro 4	-24	54.000	-67	5.000	-24	54.000	-67	35.000	1.0
	5	Arizaro 5	-24	50.000	-67	42.000	-25	10.000	-67	42.000	2.5
	6	Calilegua	-23	31.200	-64	45.000	-23	33.600	-64	39.600	0.5
		TRANSIT									4.0
5) La Rioja	1	La Antigua	-29	49.980	-66	4.980	-30	4.980	-66	4.020	0.5
	2	Ciudad	-29	19.980	-66	49.980	-29	40.020	-66	34.980	1.0
	3	Talampaya 1	-29	42.100	-68	18.600	-29	58.200	-68	9.000	0.5
	4	Talampaya 2	-29	53.400	-68	5.400	-30	2.400	-67	51.600	0.5
		TRANSIT									2.0
6) Córdoba	1	Chancaní 1	-31	22.000	-65	22.000	-31	22.000	-65	32.000	0.5
	2	Chancaní 2	-31	23.355	-65	22.000	-31	23.355	-65	32.000	0.5
	3	Chancaní 3	-31	24.708	-65	22.000	-31	24.708	-65	32.000	0.5
	4	Chancaní 4	-31	26.061	-65	22.000	-31	26.061	-65	32.000	0.5
	5	Manfredi	-31	31.260	-64	27.960	-31	50.640	-64	10.740	0.5
	6	Las Perdices	-32	50.340	-64	31.980	-32	37.020	-64	12.300	0.5
	7	Rio Cuarto Craters	-32	52.000	-64	14.000	-33	8.000	-64	21.000	0.5

Argentine Test Sites



NM EO-1 Calibration Target at Barreal Blanco, Argentina





“First Light” Image of Alaska

Why Is the ALI Pan Band Better Than the ETM+ Pan Band?

- ***Improved Radiometric resolution***
  - *Superior signal-to-noise*
  - *12-bit versus 8-bit representation of dynamic range*
- ***Inherently higher contrast measurement***
  - *ALI pan restricted to 480 – 490nm VIS spectral interval*
  - *ETM+ spans vegetation transition rise (520 – 900nm)*
- ***Smaller pixel size (IFOV)***
  - *ALI pan IFOV is 10 meters*
  - *ETM+ is nominally 15 meters (effectively 18 meters)*

Hyperion Image - Argentina

Hyperspectral DCE Acquired Dec 1, 2000

Color image produced using 3 bands in visible

Blue = band 14 (488 nm)

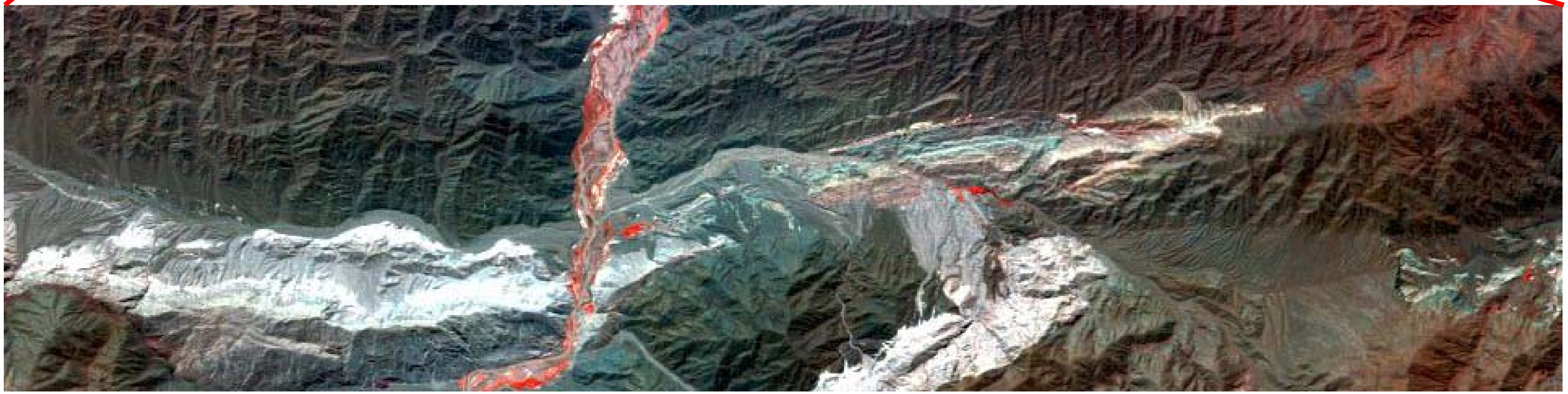
Green = band 20 (549 nm)

Red = band 38 (731 nm) (red shows areas of new spring growth)

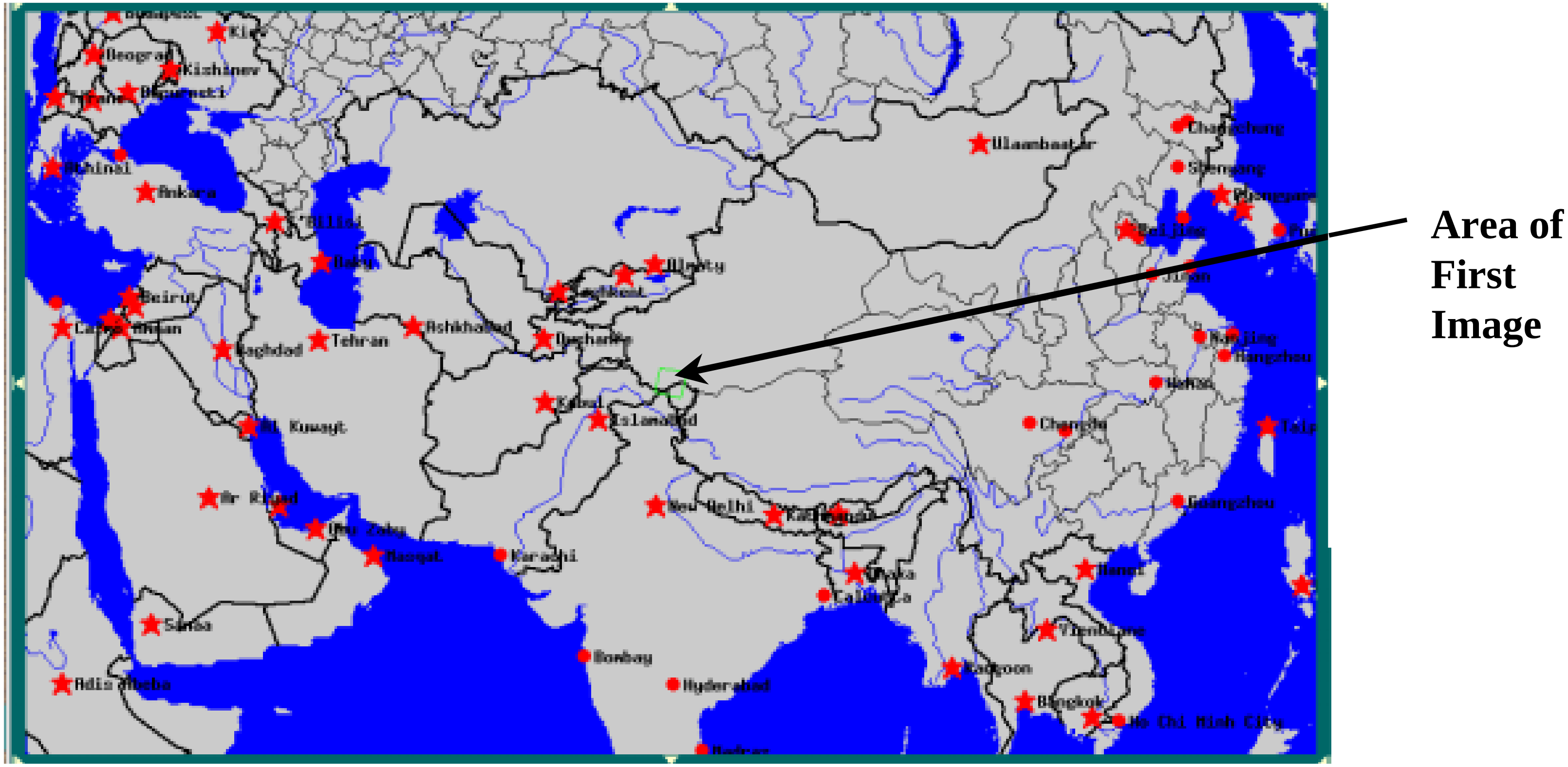
Image No. EO12000336_002002C_r1_image0su

Approx. 7.5 km wide x 65 km long

← NORTH



Area of First Hyperion Image Collection (Green Square)



Section 9

Spacecraft Technologies

- *Wideband Advanced Recorder / Processor (WARP)*
- *X-Band Phased Array Antenna*
- *Enhanced Formation Flying*
- *Carbon-Carbon Radiator*
- *Pulse Plasma Thruster*
- *Lightweight Flexible Solar Array*

Wideband Advanced Recorder Processor (WARP)

Technology Enabler

Description:

High Rate (up to 840Mbps capability), high density (48Gbit storage), low weight (less than 25.0 Kg) Solid State Recorder/Processor with X-band modulation capability.

Utilizes advanced integrated integrated circuit packaging (3D stacked memory devices) and "chip on board" bonding techniques to obtain extremely high density memory storage per board (24Gbits/memory card)

Includes high capacity Mongoose 5 processor which can perform on-orbit data collection, compression and processing of land image scenes.

Validation:

The WARP is required to store and transmit back science image files for the AC, ALI and Hyperion.

Partners:

Litton Amecom

Benefits to Future Missions:

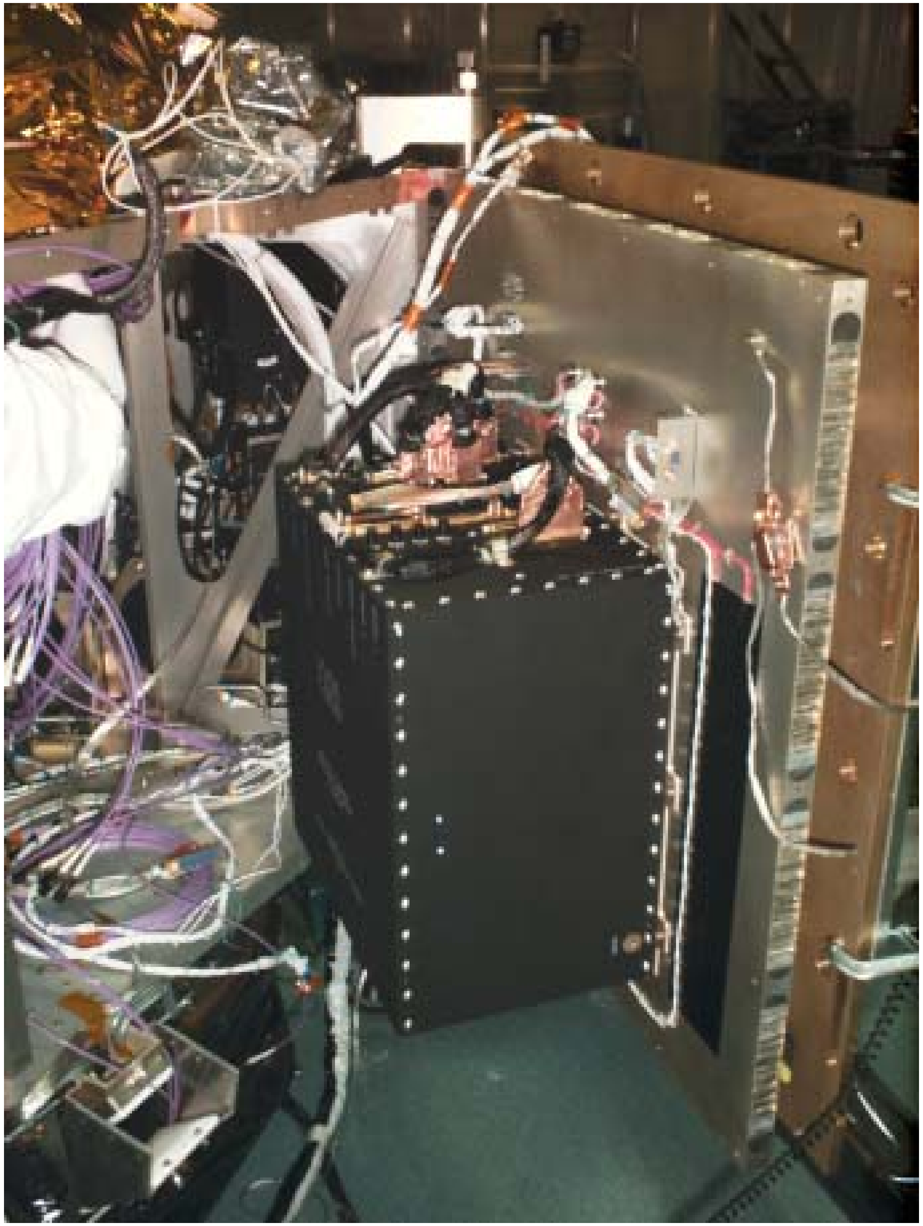
The WARP will validate a number of high density electronic board advanced packaging techniques and will provide the highest rate solid state recorder NASA has ever flown.

Its basic architecture and underlying technologies will be required for future earth imaging missions which need to collect, store and process high rate land imaging data.

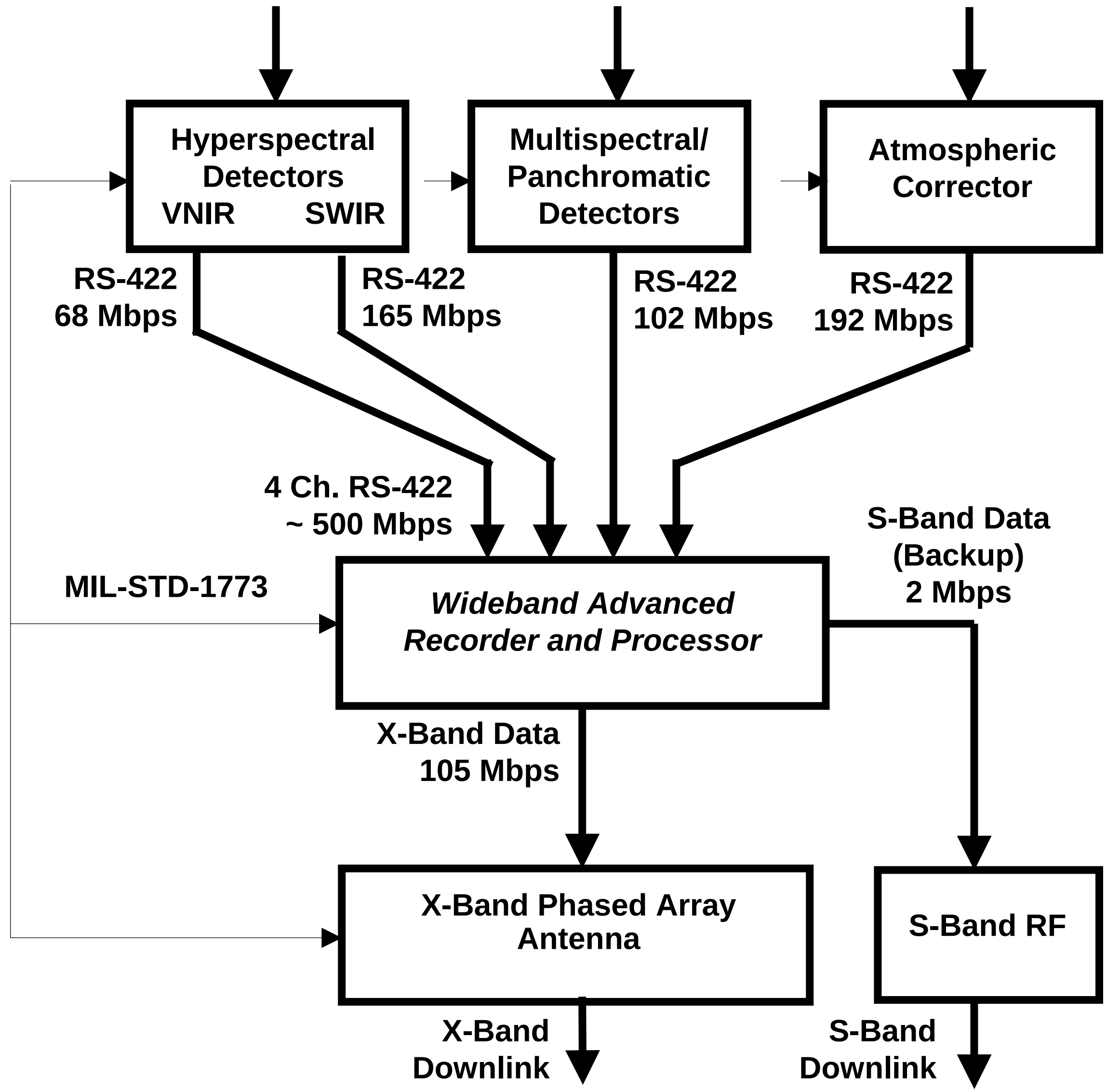
Top-Level Specifications

◆ *Data Storage:*	*48 Gbits*
◆ *Data Record Rate:*	*> 1 Gbps Burst*
	900 Mbps Continuous (6 times faster than L7 SSR)
◆ *Data Playback Rate:*	*105 Mbps X-Band (with built-in RF modulator)*
	2 Mbps S-Band
◆ *Data Processing:*	*Post-Record Data Processing Capability*
◆ *Size:*	*25 x 39 x 37 cm*
◆ *Mass:*	*22 kg*
◆ *Power:*	*38 W Orbital Average., 87 W Peak*
◆ *Thermal:*	*15 - 40 °C Minimum Operating Range*
◆ *Mission Life:*	*1 Year Minimum, 1999 Launch*
◆ *Radiation:*	*15 krad Minimum Total Dose, LET 35 MeV*

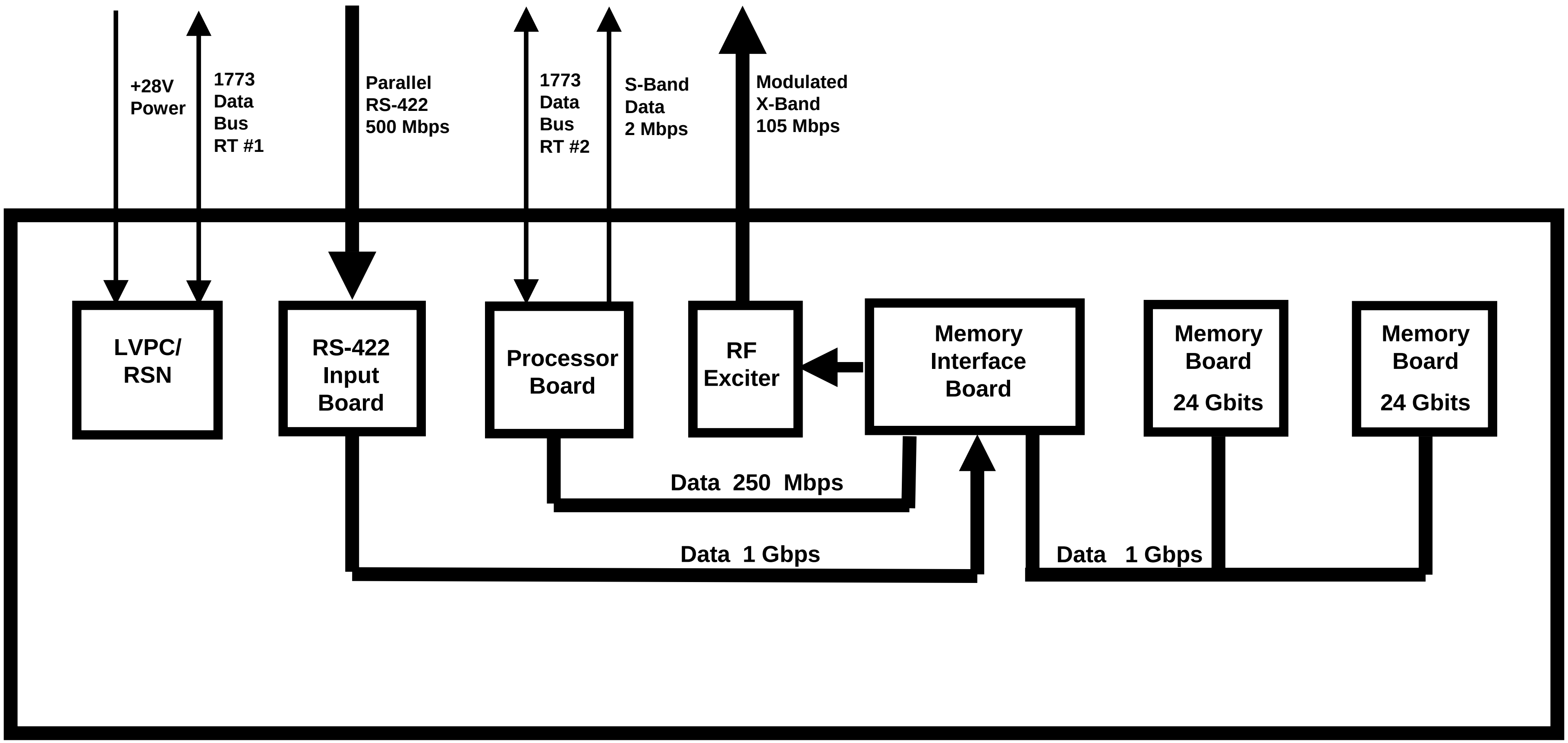
WARP on Spacecraft, Bay 1



EO-1 Flight Data System Architecture



WARP Flight Hardware Architecture



WARP Infusion Opportunities

- ***NASA owns the WARP design***
- ***WARP was built in association with Litton Amecom***
- ***WARP is particularly applicable to missions with the following:***
  - ***High ingest data rates $\leq$ 1.0 Gigabit / second***
  - ***Need for processing capability on board***
  - ***Use of phased array antenna as primary downlink***
- ***WARP was single-string for EO-1 but reliability enhancements have already been designed***
- ***Technical support to facilitate infusion is negotiable***
- ***For further information, contact:***

Terry Smith
Terrence.M.Smith.1@gsfc.nasa.gov
301-286-0651

X-Band Phased Array Antenna (XPAA)

Technology Need:

High rate, reliable RF communication subsystems

Description:

The X-band phased array antenna is composed of a flat grid of many radiating elements whose transmitted signals combine spatially to produce desired antenna directivity (gain)

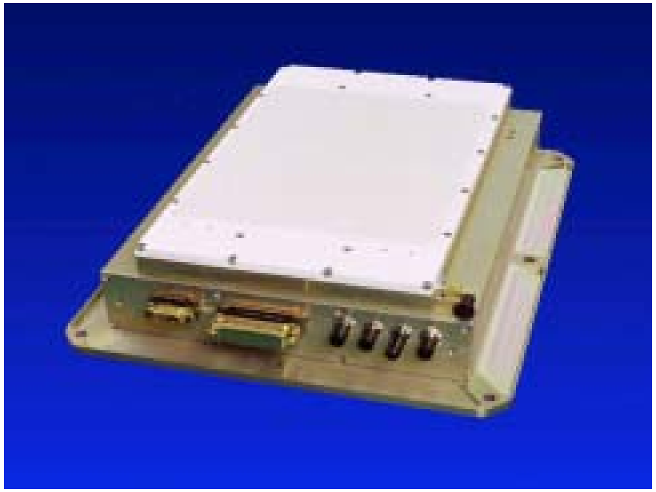
- *Avoids problems of deployable structures and moving parts*
- *Lightweight, compact, supports high downlink (100's Mbps) rates.*
- *Allows simultaneous instrument collection and data downlink.*

Validation:

The XPAA will be validated through measurement of bit error rate performance and effective ground station EIRP during science data downlinks over the lifetime of the mission.

Commercial Partners:

Boeing Phantom Works



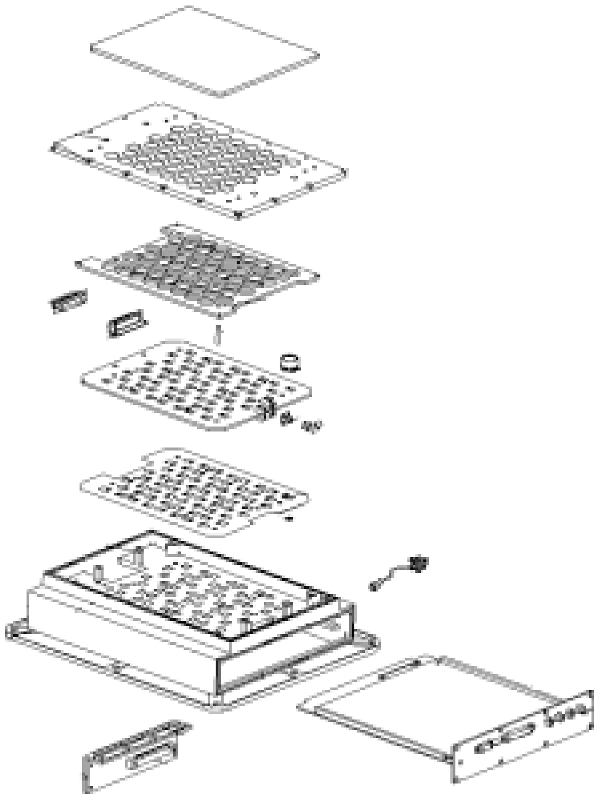
Benefits to Future Missions:

Future Earth Science missions will produce tera-bit daily data streams. The Phase Array antenna technology will enable:

- *Lower cost, weight and higher performance science downlinks*
- *Lower cost and size ground stations*
- *More flexible operations*

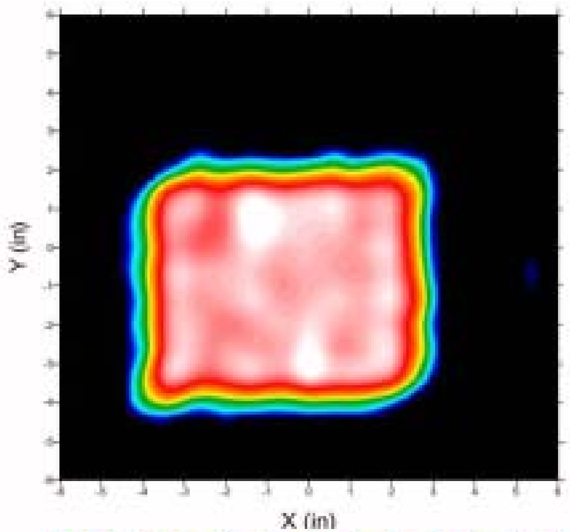
XPAA Performance Summary

- ***Frequency - 8225 MHz***
- ***Bandwidth - 400 MHz***
- ***Scan Coverage - 60 deg half-angle cone***
- ***Radiating Elements - 64***
- ***RF Input - 14 dBm***
- ***EIRP - greater than 22 dBW at all commanded angles***
- ***Polarization - LHCP***
- ***Command Interface / Controller - 1773 / RSN***
- ***Input DC Power - <58 watts over 0 to 40 C***
- ***Mass - 5.5 kg***



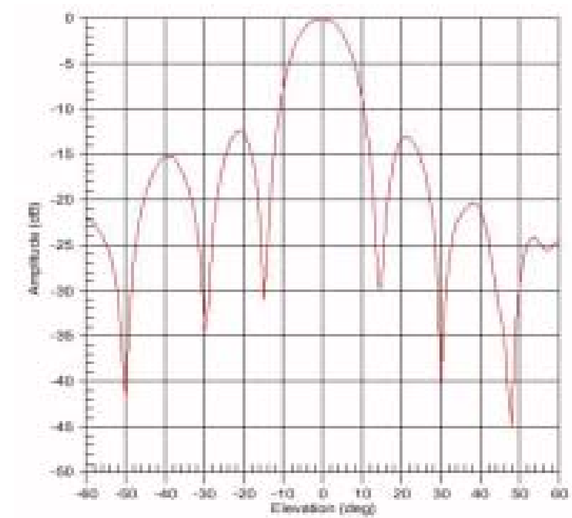
XPAA mounted on EO1, undergoing near-field scanning in the large clean room at GSFC.

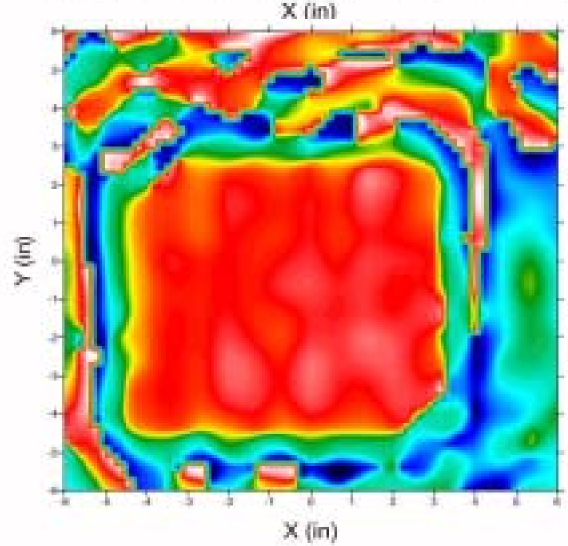
Near Field Measurement Data for the XPAA when Mounted on EO1



Aperture Amplitude

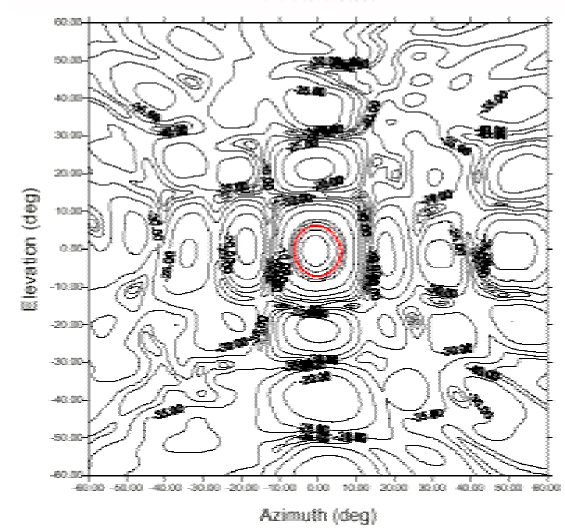
Far Field Cut





Aperture Phase

Far Field Contour



XPAA Initial Validation Summary

- *Early post-launch experience with the XPAA revealed intermittent data errors while NASA ground antennas were autotracking the X-band signal. Currently, using S-band tracking and some additional passes, all science validation data is being successfully transmitted to ground using the XPAA.*
- *A Tiger Team was established in December 2000 to find the cause:*
  - *Initial validation measurements and on-board telemetry indicate that the XPAA is operating well and as-designed*
  - *Alignment problems and other issues were found at the ground stations that are now being evaluated and rectified*
  - *This is the first X-band satellite with a Left-hand Circularly Polarized signal to be tracked by these stations*
  - *Several other commercial ground stations have had little or no difficulties in receiving the data.*
  - *All Tiger Team results will be included in the Technology Transfer Documentation*

XPAA Technology Infusion Opportunities

- ***Design is owned by Boeing Phantom Works in Seattle, WA.***
- ***Boeing is interested in the commercial sale of their phased array antennas similar to the EO-1 antenna***
  - ***The phased array antenna is applicable to missions requiring:***
    - *Low mass antenna*
    - *High reliability with graceful degradation*
    - *Agile, accurate antenna pointing with no physical disturbance to the spacecraft*
- ***NASA support to facilitate infusion is negotiable***
- ***For further information contact:***

Kenneth Perko
Kenneth.L.Perko.1@gsfc.nasa.gov
301-286-6375

Enhanced Formation Flying (EFF)

Technology Need:

Constellation Flying

Description:

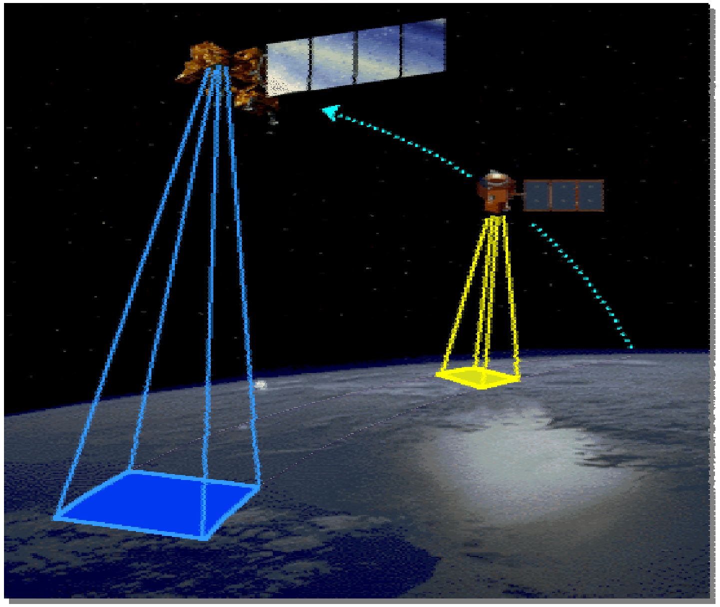
The enhanced formation flying (EFF) technology features flight software that is capable of autonomously planning, executing, and calibrating routine spacecraft maneuvers to maintain satellites in their respective constellations and formations.

Validation:

Validation of EFF will include demonstrating on-board autonomous capability to fly over Landsat 7 ground track within a +/- 3km while maintaining a one minute separation while an image is collected.

Partners:

JPL,GSFC, Hammers



Benefits to Future Missions:

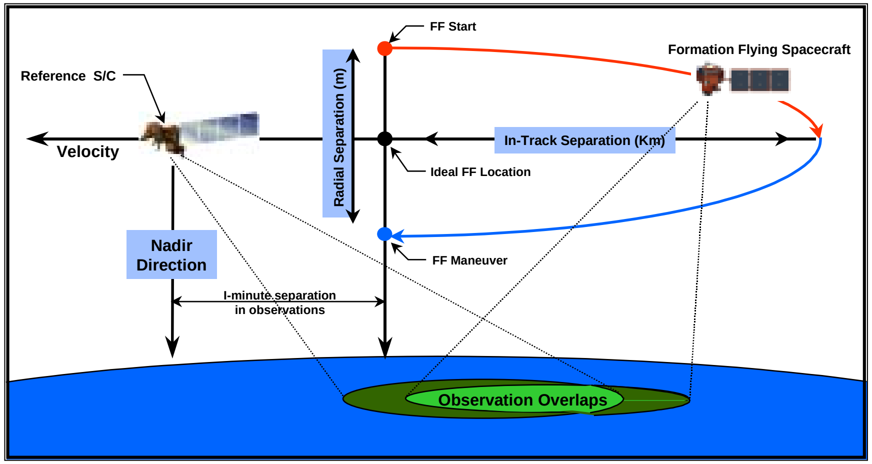
The EFF technology enables small, inexpensive spacecraft to fly in formation and gather concurrent science data in a “virtual platform.”

This “virtual platform” concept lowers total mission risk, increases science data collection and adds considerable flexibility to future Earth and space science missions.

Performance Required

- **Mission Orbit Requirements**
  - Paired scene comparison requires EO-1 to fly in formation with Landsat-7.
  - Maintain EO-1 orbit with tolerances of:
    - One minute separation between spacecraft
    - Maintain separation so that EO-1 follows current Landsat-7 ground track to +/- 3 km

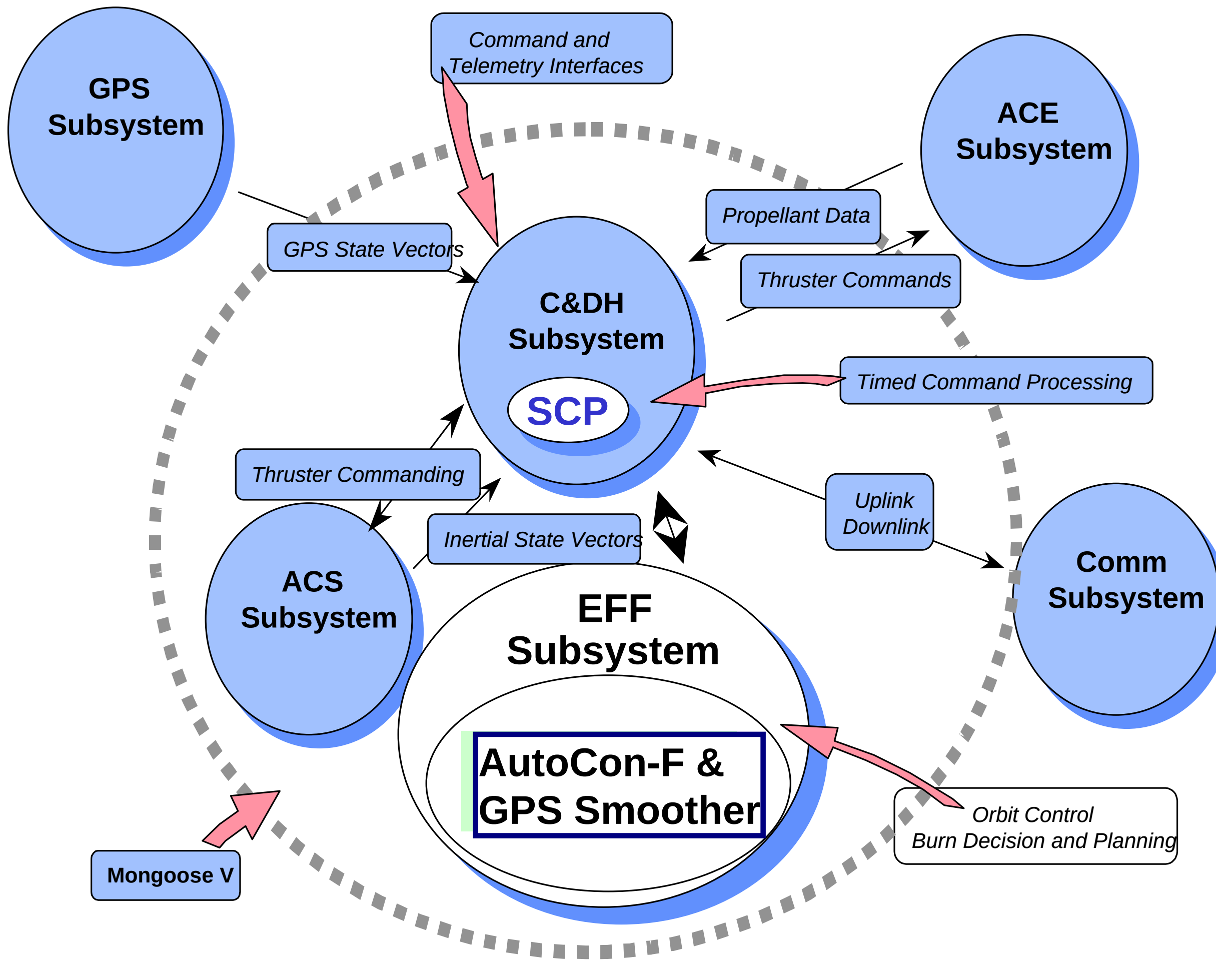
- **Derived Orbit Requirements**
  - Approximately six seconds along-track separation tolerance (maps to +/- 3km with respect to earth rotation)
  - Plan maneuver in 12 hours
- **Derived Software Constraints**
  - Code Size approximately ≈655Kbytes
  - CPU Utilization approximately <50% Average over 10 Hours during maneuver planning
  - Less than 12 hours per maneuver plan



EO-1 Formation Maneuver Frequency Is Ballistic Dependent

Subsystem Level

- **Verify**
  - *EFF*
  - *AutoCon-F*
    - GSFC
    - JPL
    - GPS Data Smoother
  - *SCP*
  - *Algorithm Flight Code Uploads for JPL into RAM*



Enhanced Formation Flying

Technology Infusion Opportunities

- ***Enhanced Formation Flying technology is owned by NASA***
- ***It is applicable to missions that require:***
  - *Constellations*
  - *"Virtual" platforms that involve the coordinated use of instruments on different spacecraft*
  - *Autonomous operations*
- ***NASA support to facilitate infusion is negotiable***
- ***For further information contact:***

Dave Folta
David.C.Folta.1@gsfc.nasa.gov
301-286-6082

Carbon-Carbon Radiator

Technology Need:

Increase instrument payload mass fraction.

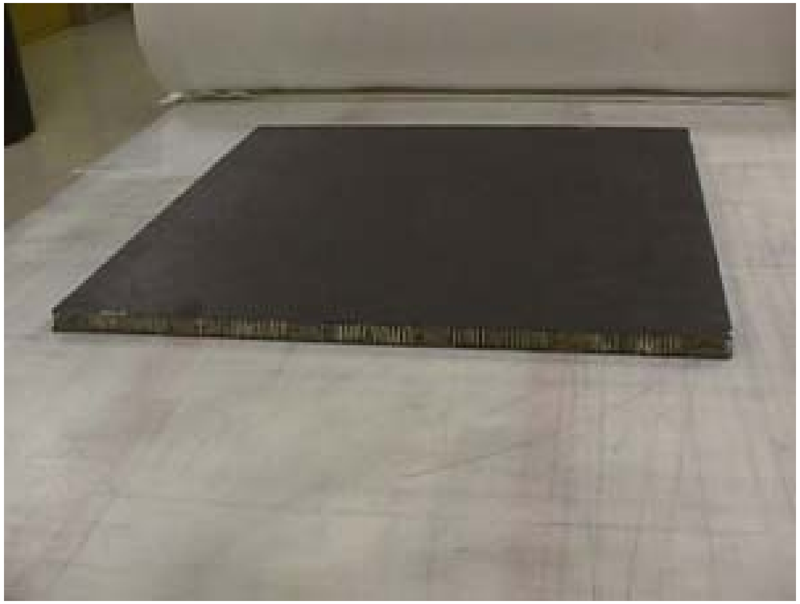
Description:

Carbon-Carbon is a special composite material that uses pure carbon for both the fiber and matrix. The NMP Earth Orbiter – 1 mission will be the first use of this material in a primary structure, serving as both an advanced thermal radiator and a load bearing structure Advantages of Carbon-Carbon include:

- *High thermal conductivity including through thickness*
- *Good strength and weight characteristics*

Validation:

EO-1 will validate the Carbon-Carbon Radiator by replacing one of six aluminum 22” x27” panels with one constructed using the C-C composite materials. Mechanical and thermal properties of the panels will be measured and trended during environmental testing and on-orbit.



Benefits to Future Missions:

This technology offers significant weight reductions over conventional aluminum structures allowing increased science payload mass fractions for Earth Science Missions. Higher thermal conductivity of C-C allows for more space efficient radiator designs.

Partners

CSRP (consortium)

Design Overview

- ***Equipment panel (Bay #4) composed of carbon-carbon facesheets and an aluminum honeycomb core***
- ***Supports the LEISA and PSE***
- ***Measures 28.62 x 28.25 x 1.00 in***
- ***Mass of 3.12 kg***
- ***Flight unit and spare***
- ***Design stable since CDR***

Performance Required

- ***Mass - Less than 2.5 kg***
- ***Stiffness - First mode frequency greater than 100 Hz when hard-mounted to the S/C***
- ***Strength - Inertial loading***
  - ***Simultaneous quasi-static limit and S/C interface loads***
    - *15 g acceleration in any direction*
    - *Shear load of 16,100 N/m*
    - *Edge normal load of 19,500 N/m*
    - *Panel normal load of 1,850 N/m*
  - ***Maximum fastener forces at the S/C attachment points***
    - *Maximum tension force of 25 N*
    - *Maximum shear force normal to panel edge of 135 N*
    - *Maximum shear force parallel to panel edge of 115 N*
- ***Strength - Thermal loading***
  - ***On-orbit temperature variations ranging from -20°C to +60°C***

Carbon-Carbon Radiator

Technology Infusion Opportunity

- ***Design is owned by Carbon-Carbon Spacecraft Radiator Partnership (CSRP)***
- ***This technology is applicable to missions requiring:***
  - ***Lightweight, efficient radiators with favorable structural properties***
  - ***Structural properties and thermal properties can be balanced in the manufacturing process***
- ***The CSRP is interested in providing these radiators to interested parties***
- ***NASA support to facilitate infusion is negotiable***
- ***For more information contact:***

Dan Butler
Charles.D.Butler.1@gsfc.nasa.gov
301-286-3478

Pulse Plasma Thruster (PPT)

Technology Need:

Increased payload mass fraction and precision attitude control

Description:

The Pulse Plasma Thruster is a small, self contained electromagnetic propulsion system which uses solid Teflon propellant to deliver high specific impulses (900-1200sec), very low impulse bits (10-1000uN-s) at low power.

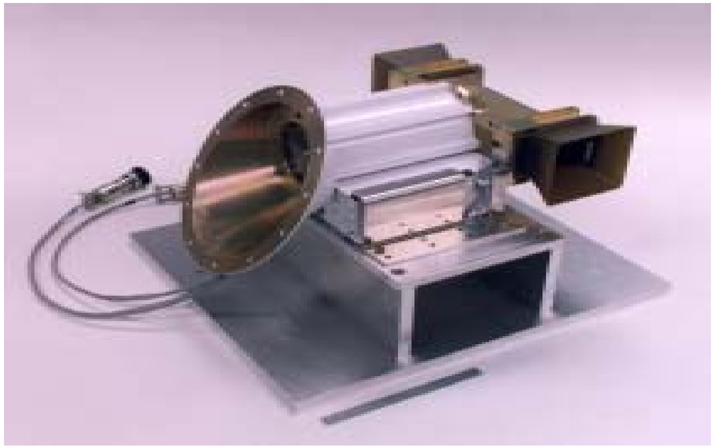
Advantages of this approach include:

- *Ideal candidate for a low mass precision attitude control device.*
- *Replacement of reaction control wheels and other momentum unloading devices. Increase in science payload mass fraction.*
- *Avoids safety and sloshing concerns for conventional liquid propellants*

Validation:

The PPT will be substituted (in place of a reaction wheel) during the later phase of the mission (month 11). Validation will include:

- *Demonstration of the PPT to provide precision pointing accuracy, response and stability.*
- *Confirmation of benign plume and EMI effects*



Benefits to Future Missions:

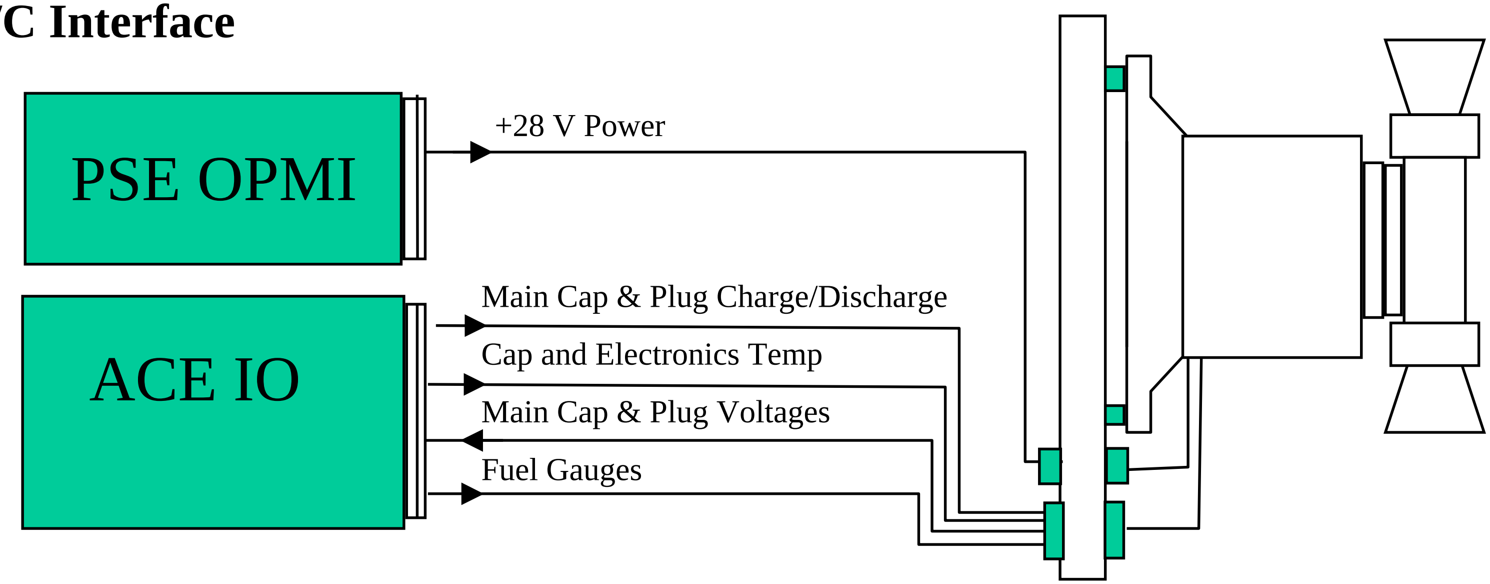
The PPT offers new lower mass and cost options for fine precision attitude control for new space or earth science missions

Partners

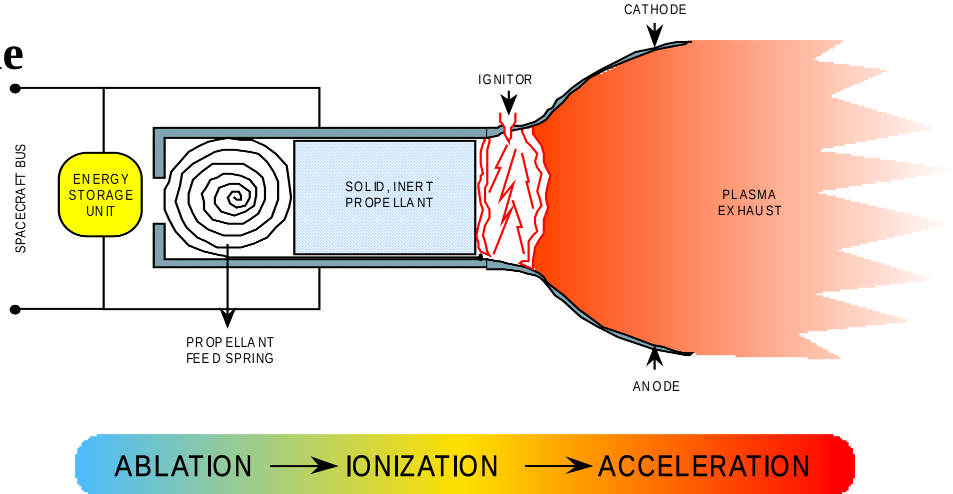
GRC, Primex, GSFC

PPT Design

S/C Interface



Technology Principle



Pulse Plasma Thruster

Technology Infusion Opportunity

- ***Design is owned by Primex***
- ***Validation scheduled for October / November 2001***
- ***EO-1 unit developed at the Glenn Research Center***
- ***Applicable to missions requiring:***
  - ***Low mass, precision attitude control***
  - ***Highly reliable***
- ***Primex will provide similar units to interested parties***
- ***NASA support to facilitate infusion is negotiable***
- ***For more information contact:***

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Lightweight Flexible Solar Array (LFSA)

Technology Need:

Increase payload mass fraction.

Description:

The LFSA is a lightweight photovoltaic(PV) solar array which uses thin film CuInSe2 solar cells and shaped memory hinges for deployment. Chief advantages of this technology are:

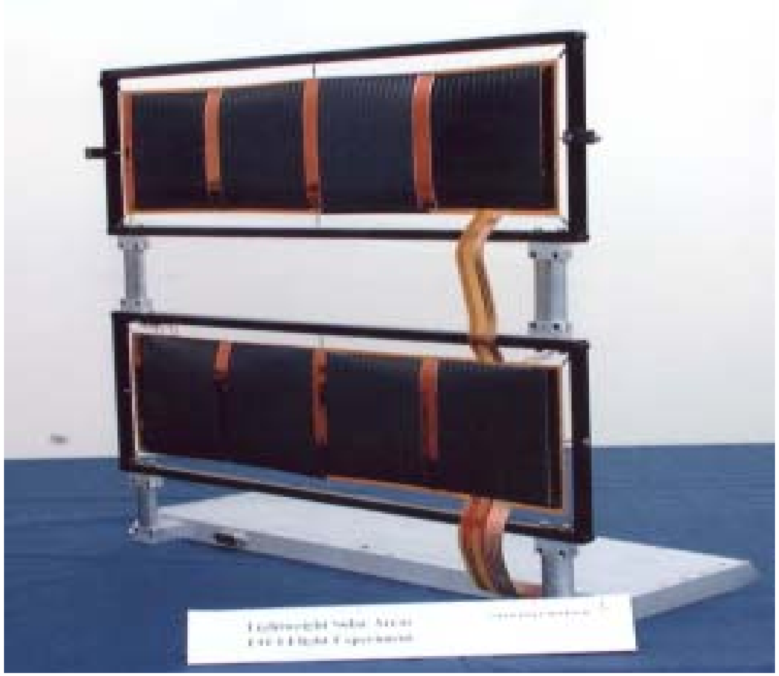
- *Greater than 100Watt/kg specific energies compared to conventional Si/GaAs array which average 20-40 Watts/kg.*
- *Simple shockless deployment mechanism eliminates the need for more complex mechanical solar array deployment systems. Avoids harsh shock to delicate instruments.*

Validation:

The LFSA deployment mechanism and power output will measured on-orbit to determine its ability to withstand long term exposure to radiation, thermal environment and degradation due to exposure to Atomic Oxygen.

Partners

Phillips Lab, Lockheed Martin Corp



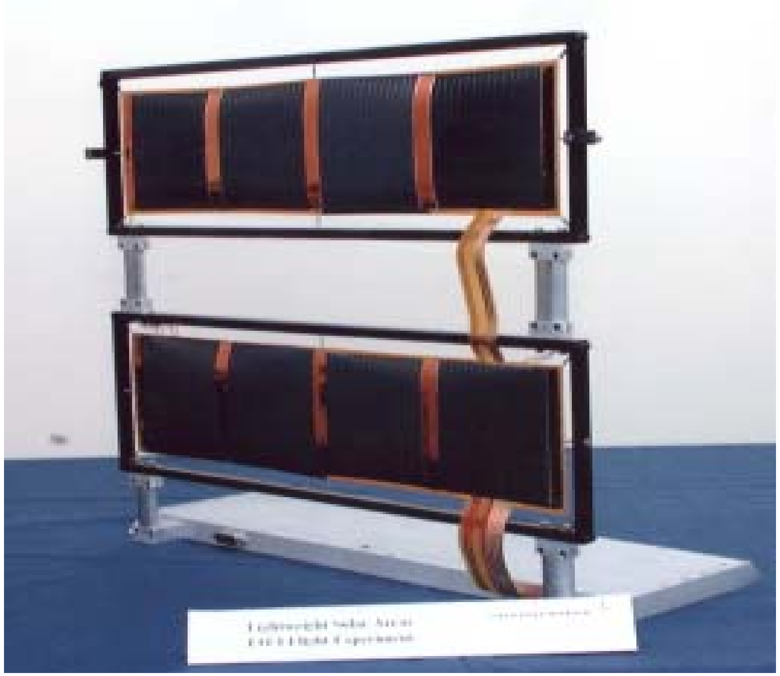
Benefits to Future Missions:

This technology provides much higher power to weight ratios (specific energy) which will enable future missions to increase science payload mass fraction.

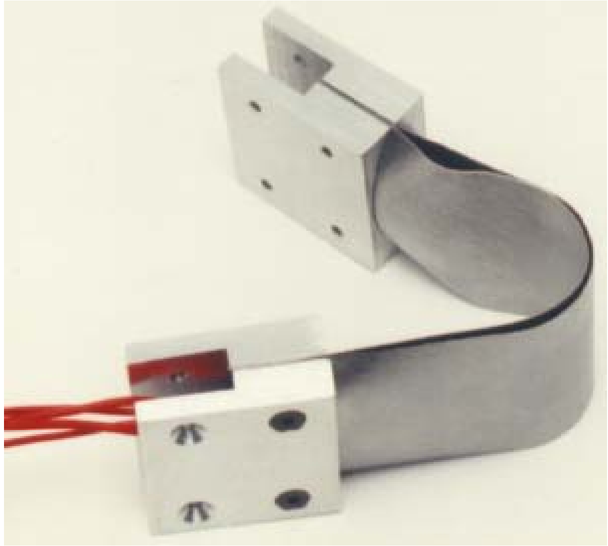
Description

- ***Copper Indium Diselenide ($CuInSe_2$ or CIS) Thin-Film Solar Cells***
- ***Deposited on a Flexible Kapton Blanket suspended in a Composite Frame***
- ***Frame Deployed Using Shape Memory NiTi Alloys and a Launch Restraint Device***
- ***Advantage: Increase solar array w/kg (from typical 40 w/kg to >100 w/kg), increase science payload mass fraction***
- ***Partners: AFRL (Kirtland AFB, NM), NASA/LaRC, Lockheed Martin (Denver, CO)***

Description *(continued)*



LFSA FLIGHT UNIT



SMA - STOWED

SMA - DEPLOYED

Lightweight Flexible Solar Array

Technology Infusion Opportunities

- ***Design is owned by Lockheed Martin***
- ***Developed by Air Force Research Lab***
- ***Applicable to missions requiring low mass solar array***
- ***Shaped memory hinges provide simple, shockless deployment***
- ***Lockheed Martin will provide similar systems to interested parties***
- ***NASA support to facilitate infusion is negotiable***
- ***For more information contact:***

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Section 10

Next Steps and Near-Term Schedule

Operational Phases

- ***Launched on November 21, 2000***
- ***Initial Operations:***
  - *First several orbits to complete essential spacecraft checkout*
  - *Approximately 15 days to fully complete technical checkout (22 days to get into formation one minute behind Landsat)*
- ***Instrument Checkout***
  - *Full instrument checkout involving imagery to validate technical performance*
  - *Requires approximately 60 days*
- ***Nominal Ops***
  - *Science validation starts after Instrument Checkout*
  - *Minimal Mission completed in about 120 days*
  - *All validations completed after 330 days*
- ***Extended Mission:***
  - *Planning starts at 120 days*
  - *Decision at 180 days*
  - *Start at 330 days*

Next Steps

- ***EO-1 web site: http://eo1.gsfc.nasa.gov***
- ***Contains a section entitled "EO-1 Technology Transfer & Infusion":***
  - *Background information*
  - *Presentations*
  - *Mission status*
  - *Schedule of events*
  - *Contact information*
  - *Technology Transfer Documentation as available*
- ***To discuss infusion opportunities use the contacts provided today***
- ***To discuss your participation in an EO-1 Extended Mission, contact:***
  - *Granville Paules: 202-358-0706*
  - *Bryant Cramer: 301-286-0644*